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IMPROVED NERVE CUFF ELECTRODE RECORDINGS BY SUB-THRESHOLD ANODIC CURRENTS

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***Abstract*—Computer simulations indicate that the propagation velocity of action potentials in a length of a nerve axon can be decreased by sub-threshold extracellular anodic currents. This phenomenon can be used to increase the amplitude of whole nerve recordings made with a short cuff electrode with circumferencial metal bands, since larger propagation delays between the bands result in larger recorded signals. Computer simulations predicting the slowing effect of anodic currents and the experimental data verifying the simulations are presented. The increase in the amplitude of nerve signals (fivefold), recorded experimentally from a short cuff, is demonstrated.**

INTRODUCTION

The signal amplitudes increase with increasing cuff lengths when a cuff electrode with circumferencial metal bands (as the contact points) is used to record peripheral nerve activity [1]. This effect can be attributed to the increase in propagation delay between the bands. With short cuff lengths, it is mostly the slow (i.e. small) fibers that contribute to the recordings. However, the maximal dissectable length of the nerve places a limitation on the cuff length in most *in vivo* studies. Computer simulations indicate that anodic currents decrease the propagation velocity of action potentials by hyperpolarizing the membrane and increasing the time required by the membrane to reach the stimulation threshold. Thus, the propagation delay between the recordings obtained from the individual band electrodes that are placed along the cuff increases, thereby making the cuff appear longer than its physical size. Thus, we propose that anodic currents can be used to increase the amplitude of whole nerve recordings made with a short cuff electrode.

METHODS

The effect of applied anodic currents on the propagation of action potentials of a single myelinated nerve fiber (an axon of 10 μm caliber and of 10 cm length, i.e. 101 nodes) is demonstrated by computer simulations (Figure 1). The simulations are done using NEURON [2]. The active behavior of the cell membrane at each node of Ranvier is simulated using an active mammalian nerve model [3]. The internodal sections are simulated by a single intracellular resistivity element (Ra). The extracellular voltage profile along the axon due to a monopolar electrode placed in an infinite conductive medium is calculated (Figure 2). Discrete current sources proportional to sampled version of the second order spatial difference of this voltage profile are applied to the nodes intracellularly and the nodes are connected together at the extracellular site. This was shown to be equivalent to applying discrete voltage sources at the extracellular site as the sampled version of the extracellular voltage profile [4]. A stimulation pulse (10 μsec, 20 nA) is applied at the left end of the axon. The temporal waveform of the transmembrane voltage is calculated at each node as the action potential propagates. The conduction velocities are calculated between consecutive nodes by taking the reciprocal of the time delay between the peaks of the voltage waveforms. The cumulative delay is defined as the total time period from the time of stimulation to the peak of activity at a given node.

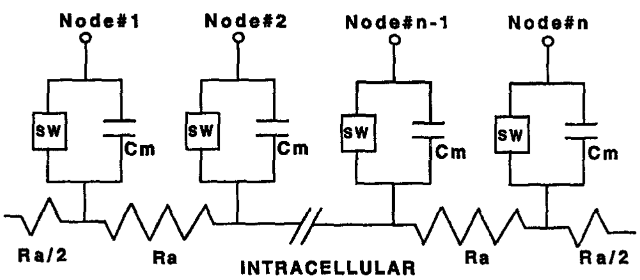

FIGURE 1: The discrete axon model used by NEURON. The passive parameters are: Intracellular specific resistivity = 54.7 Ωcm, membrane capacitance (Cm) =2.5 μF/cm²·, outer diameter with the myelin sheath = 10 μm, axon diameter = 6 μm, node length = 1.5 μm.

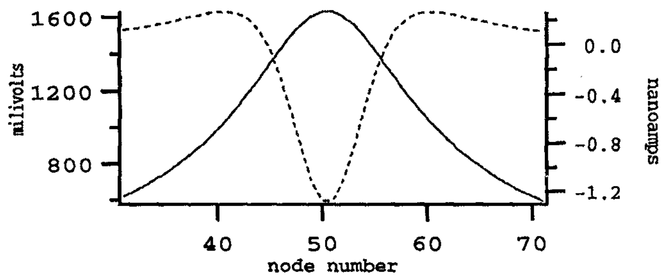

FIGURE 2: Extracellular voltage profile (continuous line) along the axon due to a monopolar electrode (anodic, I=300 mA) placed centrally at a distance of 8 mm within an infinite volume conductor, and the amplitudes of discrete current sources (dashed line) applied intracellularly to simulate the same effect..

In vitro experiments are conducted by placing a phrenic nerve (diameter=1 mm) from a pig (20 kg) and three cuff electrodes in a bath (T=24.5°C) filled with Krebs solution (Figure 3). The cuff electrodes are made with silastic tubing and platinum contact elements. Two hypotheses are tested with the experiments: (1) that the action potentials do slow down with anodic currents, (2) that the signal amplitudes recorded by a short cuff (the three middle bands of cuff #2) increase as a result of the increase in the propagation delay.

The nerve is stimulated with a current pulse at the threshold (10 μsec, 40 μA) through cuff #1 and anodic

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current is applied through the two longitudinal sets of contact points within cuff #2 with respect to the outer bands. The amplitude of anodic current is varied from 0 μA to 30 μA in increments of 4 μA. Further increases in the current results in blocking of some large fibers as indicated by a decrease in the recorded amplitudes from cuff #3.

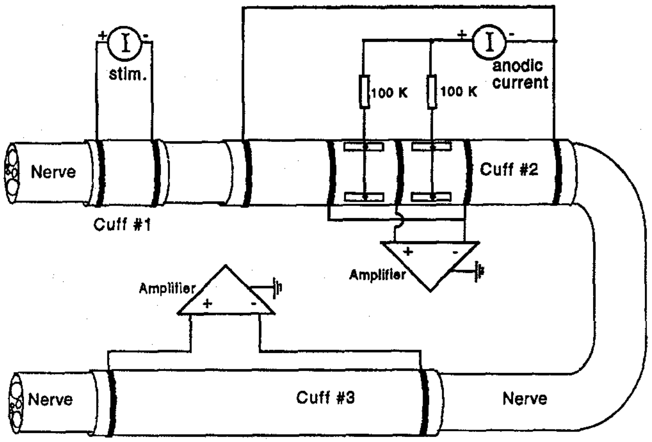

FIGURE 3: The set-up used for the experiments. Three cuff electrodes are placed along the nerve: a stimulation cuff (cuff #1, contact separation is 5 mm), an anodic current&recording cuff (cuff #2, five bands with 5 mm separation between each, and longitudinal contact points each 4 mm long as shown), and a recording cuff (cuff #3, two bands with 24 mm separation). Resistors (100 KOhm) are used to split the current evenly between the electrodes.

RESULTS

The conduction velocity profile predicted by the simulations is shown in Figure 4. The velocity can be decreased to a value as low as 40% of its normal value in the case of maximal anodic current amplitude (30 μA).

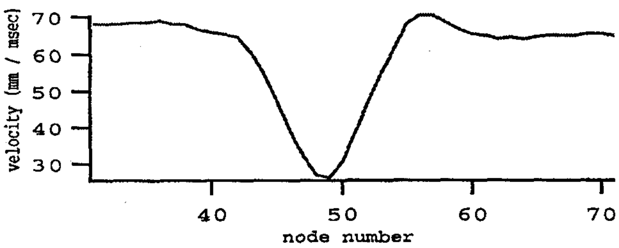

FIGURE 4: The conduction velocity calculated along the axon model shown in Figure 1. Only the velocities between the nodes 30 and 70 are plotted.

The compound action potentials recorded from cuff #3 are shown in Figure 5A. The delay in the recordings without significant change in the temporal waveform indicates an overall decrease in the propagation velocity of the fibers being stimulated. The cumulative delay due to the slowing of action potentials at 30 μA anodic current is 0.5 msec.

The compound action potentials recorded from the middle three bands of cuff #2 are shown in Figure 5B. The peak-to-peak amplitude for zero anodic current is small (24 mV) due to the small separation between the bands (5 mm). The electrodes record only from the slowest (i.e. small) fibers in this case. As the anodic current amplitude is increased, a greater number of large (i.e. fast) fibers are slowed down and begin to contribute to the signal. Thus, the cuff starts to record also from the large fibers and the signal amplitude is increased. The increase in the amplitude of compound action potentials is about fivefold (from 24 to 128 $\mu V_{peak\text{-}to\text{-}peak}$) for the 30 μA anodic current.

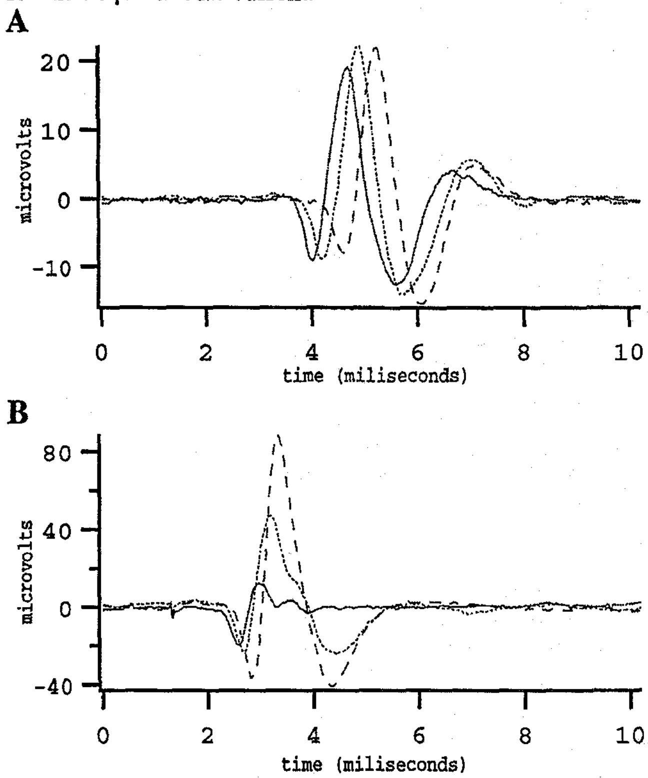

FIGURE 5: Compound action potentials recorded A) from cuff #3 in bipolar configuration and B) from cuff #2 in tripolar configuration for the anodic currents : 0 μA (continuous line), 15 μA (dotted line), and 30 μA (dashed line).

CONCLUSIONS

The experimental data confirmed the predictions of the simulations that the action potentials slow down and the amplitudes recorded with a short cuff increase with the anodic currents. We conclude that this method can be used to improve the quality of acute recordings where the size of the cuff is limited. The large increases in amplitudes with anodic currents suggest that this method can also be used for selective recordings by specifically hyperpolarizing a local cluster of fibers (e.g. a fascicle) in the nerve trunk, thus, increasing the signals recorded only from that cluster while ignoring the activity from the others.

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