

Intrafascicular electrodes for nerve stimulation

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ABSTRACT

We have designed a new type of intrafascicular, implanted electrode for stimulating peripheral nerves to elicit muscle contraction. The electrode requires low current to stimulate the nerve fibers, provides a fine control of muscular force, and causes little or no tissue reaction. It is of potential use for Functional Neuromuscular Stimulation [1].

INTRODUCTION

The overall aim of this project is to ascertain whether a new type of electrode, implanted into fascicles of peripheral motor nerves, is effective for acute and chronic stimulation of motor neurons to produce stable and graded control of muscle forces. The intrafascicular approach requires low levels of current to elicit muscle contraction and provides good control of force. In addition it allows one to select a stimulation site that minimizes movement and stress on the nerve and electrode leads.

METHODS

Intrafascicular electrodes are threaded longitudinally inside the fascicle of motor nerves. These bipolar electrodes are made from Teflon insulated, 25 μm diameter, 90% Pt - 10% Ir wires. Approximately 1 mm of insulation is removed about 20 mm back from the ends of the wires. The end of one wire is attached to a sharpened tungsten needle with cyanoacrylate adhesive, and the two wires are threaded through a silastic tube. The needle is used to thread the wire into the fascicle; the silastic tube is used to protect the the wires from the insertion point in the nerve to the exit point in the skin. This type of electrode has already been shown adequate for recording activity in peripheral

nerves [2]. Muscle activation threshold was measured in anesthetized rats by applying 200 μsec duration pulses through a regulated current isolation unit. Both single pulses and trains of pulses (50 Hz for 400 msec) were used. Implants were left in place for three months and tested periodically during this time. Unlike natural stimulation, in which the smaller axons are recruited first, the electric field generated by the electrode activates the bigger fibers first. This could result in a problem in the control of muscle force. So it is important to verify the "control" properties of our electrodes by studying their recruitment properties.

We measured the contraction force generated in the gastrocnemius (fast) and soleus (slow) muscles in cats anesthetized with sodium pentobarbital. Each muscle was exposed and the distal tendon was dissected and connected to a strain gauge. An electrode was then implanted into a fascicle innervating the prepared muscle. The stimuli consists of current controlled trains (50 Hz, 500 msec duration) of square pulses of 200 μsec duration. The amplitude was systematically varied between threshold and the value that gave maximal tetanic force. The experiment was repeated with three different preloads on the muscle and we measured the contraction force exerted above the preload.

Among the many factors that influence the muscle response, we also focused on the effect of activation of muscle spindles and tendon organs on the muscle response. In order to quantify the importance of the spinal reflex, we performed the same set of experiments with the same preloads, but with the nerve crushed proximally to the electrode. The nerve was crushed and not cut in order to maintain the same electrical pathway for current flow from the electrode.

RESULTS

Biocompatibility The average current threshold was near 15 μA ; this corresponds to a charge density per pulse on the order of 4 $\mu\text{C}/\text{cm}^2$. These currents are more than one order of magnitude below levels which have been shown to be safe in stimulating nerves at physiologically meaningful levels with cuff electrodes [3], and the individual pulse charge densities are well below those shown to be safe for both neural tissue and electrode integrity in studies on cortically implanted platinum electrodes [4].

Over the course of three months, the threshold value remained fairly constant. Histological examination of tissue implanted for this period showed little adverse tissue reaction, indicating that minimal damage is done to the nerve fibers by the implant procedure or the electrodes. In the best implants it was difficult to distinguish between the site where the wire was implanted and intrafascicular blood vessels.

Recruitment Typical results from an experiment on recruitment in the superficial head of the lateral gastrocnemius are shown in the figure below. Note that, for a fixed current, a higher preload produced a greater force. Crushing the nerve reduced the maximal force produced by the muscle. This is probably due to the interruption of the spinal reflex, since in normal nerves the electrical stimuli excite not only the motor neurons, but the spindle fibers as well. This allows the spread of the excitation to other nerve fibers in the motoneuron pool.

FUTURE DEVELOPMENTS

Our plans for the future are to characterize in more detail the role played by spindle fibers

and Golgi tendon organs during functional electrical stimulation of peripheral nerves. We also plan to identify the stimulus parameters that give an optimal control of muscle force.

CONCLUSIONS

Our electrodes induce minimal adverse reaction in the surrounding tissue and utilize current values that are suitable for safe stimulation. The electrodes also allow fine control of the muscle force with a relatively broad (from 40 μA to 100 μA) current range, which suggests that they may be suitable for clinical applications.

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