Proceedings of The First Joint BMES/EMBS Conference **Serving Humanity, Advancing Technology** Oct. 13-16, '99, Atlanta, GA, USA

Muscle Recruitment by Intramuscular vs. Nerve Cuff Electrical Stimulation

K. Singh, F.J.R. Richmond and G.E. Loeb
MRC Group in Sensorimotor Neuroscience and Dept. of Physiology
Queen's University, Kingston, ON, Canada K7L 3N6

ABSTRACT

Functionally useful reanimation of paralyzed limbs depends on achieving reliable fine-control of muscle recruitment and force. We have used force and EMG recordings and histochemical analysis to investigate the recruitment properties of intramuscular (IM) and nerve cuff (NC) electrodes implanted acutely or chronically in cat hindlimbs, focussing on stimulation intensities and frequencies of interest for functional electrical stimulation (FES). NC stimulation produced very steep and surprisingly unstable recruitment, mostly of the fast-fatiguable (FF) motor units (MUs). IM stimulation produced more gradual, reliable and less fatigable recruitment of a mix of MUs that tended to be localized in neuromuscular compartments.

INTRODUCTION

We have developed wireless, injectable, microstimulators (called BIONs™) that receive power and digital command data by inductive coupling from an external RF coil [1]. This IM approach is intended to serve FES applications, many of which require muscles to produce moderate, reproducible forces. In this study, we compared the recruitment properties of IM electrodes with the BION geometry to NC electrodes.

METHODS

Stimulation Electrodes

IM electrodes had bipolar contacts wrapped around either end of a silicone tube 2 mm diameter by 16 mm long, implanted in medial gastrocnemius (MG) muscle. NC electrodes had bipolar contacts molded 10 mm apart inside a 3 mm i.d. silicone tube, implanted on the sciatic nerve. Sixteen cats were implanted with both electrodes either acutely or 3 weeks prior to testing. Nerve hook electrodes were also tested acutely in some animals.

Physiological Measurements of Recruitment

Isometric force was recorded from the achilles tendon. M-waves following each stimulation pulse were recorded by bipolar wires threaded transversely across the entire muscle belly. Stimulation currents (0.1 ms/phase) for IM and NC electrodes were adjusted to produce 20% of the supramaximal twitch force achievable via the NC electrodes.

Histochemical Analysis of Recruitment

The intramuscular distribution and fiber types of recruited MUs were explored by using repeated stimulus trains (40 pps, 330 ms long, 1/s until completely fatigued) to deplete muscle fibers of glycogen. Adjacent sections were stained for glycogen by PAS and for myosin ATPase for fiber typing.

RESULTS

Recruitment curves for NC stimulation were very steep. Typically less than 5% range of NC stimulus current modulated twitch force from 10% to 50% of supramaximal force; such modulation typically required 300-1000% increases in IM current.

Repetitive stimulation through IM electrodes resulted in an initially rapid fatigue followed by fairly stable force production at 20-30% of the initial level. Histology revealed a mix of depleted fiber types confined to about 30% of the muscle area. Similar stimulation through NC electrodes produced rapid fatigue to near zero force, but there were often abrupt fluctuations in the force level during the experiment. Glycogen depletion was widely scattered and appeared to be incomplete. Both acutely and chronically implanted NCs appeared to be very sensitive to small amounts of motion.

NC recruitment was also unstable even within trains. Figure 1 shows a pattern typical of most NC and hook electrodes. No such fluctuations were seen for IM stimulation despite the much larger motion in the vicinity of the electrodes.

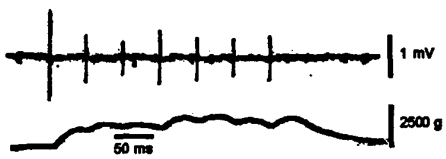

Figure 1: M-waves (top trace) and force records (bottom trace) from MG during a 20 pps train of 7 stimuli with amplitude adjusted to produce 20% of maximal force for single twitches delivered to the sciatic nerve via NC electrode. Note large first M-wave followed by fluctuating recruitment, resulting in irregularly waxing and waning force.

DISCUSSION

The steep recruitment curve of NC stimulation makes this method highly sensitive to fluctuations in neural excitability that may occur through accumulation of K^+ during trains at physiological frequencies. IM stimulation provides more stable and less fatigable force production at moderate force levels.

REFERENCE

[1] T. Cameron, G.E. Loeb, R.A. Peck, J.H. Schulman, P. Strojnik and P.R. Troyk. Micromodular implants to provide electrical stimulation of paralyzed muscles and limbs. IEEE Trans. Biomed. Engng., 44:781-790, 1997.