FUNCTIONAL CONTROL OF JOINT TORQUE WITH A CUFF ELECTRODE

Warren M. Grill, *Student Member*, and J.Thomas Mortimer

Applied Neural Control Laboratory
Department of Biomedical Engineering
Case Western Reserve University, Cleveland, Ohio 44118-4912

***ABSTRACT*- Three acute experiments were conducted on adult cats to test the performance of a multiple contact nerve cuff electrode in the control of joint torque. A cuff implanted on the sciatic nerve allowed selective and progressive control of the magnitude and direction of the isometric torque about the ankle joint. Use of transverse field steering current improved the selectivity of torque control and increased the dynamic range of torque production. The results suggest that the multiple contact nerve cuff will be a useful component of future motor prosthesis systems.**

I. INTRODUCTION

Electrical activation of intact lower motor neurons is a method to restore motor function in paralyzed persons. Present motor prostheses employ either coiled wire intramuscular electrodes or epimysial electrodes. At least one electrode is required to activate each muscle, thus this approach is limited by the number of electrodes that can be physically tolerated, and by the number of available stimulator channels. Muscle-based electrodes also suffer from material fatigue failure, displacement, and recruitment properties that depend on muscle length [1]. It is clear that alternative methods of stimulation are required to advance the function and widespread use of motor prostheses.

Nerve cuff electrodes overcome many of the problems of muscle based electrodes. They can be placed in areas of low mechanical stress, they should not suffer from length-dependent recruitment properties, and they provide a stable interface between the electrodes and the excitable tissue.

In the past, nerve cuff electrodes have been used predominantly for discrete on-off control of entire nerve trunks for applications such as electrophrenic respiration [2] and correction of footdrop [4]. We have recently designed a multiple contact spiral nerve cuff that enables selective and graded activation of discrete regions of a peripheral nerve trunk, and thus allowed control of four muscles with a single electrode [5]. The goal of the work reported here was to investigate the control of joint torque with the multiple contact nerve cuff electrode. We hypothesized that by selectively activating discrete portions of the sciatic nerve, we could control the magnitude and direction of the torque developed about the ankle joint.

This work was supported by a grant from the Paralyzed Veterans of America Spinal Cord Research Foundation.

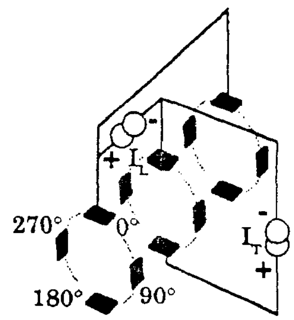

Fig. 1: Geometry of the multiple contact nerve cuff electrode. I_L is the longitudinal stimulus current, and I_T is the transverse field steering current. Each of the four tripoles was connected as shown.

II. METHODS

Acute experiments were conducted on three adult cats anesthetized with ketamine hydrochloride (30 mg/kg, I.M.) and maintained with sodium pentobarbital (30 mg/kg, I.V.). Animals were intubated and body temperature was maintained at with a heating pad. A silicone rubber spiral nerve cuff [5] containing 12 individually addressable platinum electrode contacts (Fig. 1) was implanted on the right sciatic nerve approximately 1cm proximal to the popliteal fossa. The sciatic nerve at this level contains approximately 7 fascicles that innervate the muscles that produce torques about the ankle joint. The animal was placed in a rigid frame and the right hip and knee were immobilized at 120° and 90°, respectively. The right paw was attached to a force and moment transducer with the ankle joint angle set at 90°. The transducer was set-up to measure the three dimensional torque about the ankle joint.

Isometric twitch torques elicited by single 10 µsec monophasic constant current pulses were low pass filtered (f_{3dB}=100Hz), amplified, and sampled (f_s=200Hz). Recruitment curves of peak twitch torque as a function of longitudinal current amplitude (I_L in Fig. 1) were collected for each of the four tripoles. The magnitude of the transverse steering current (I_T in Fig. 1) was set to 0, 45% of the transverse excitation threshold, or 90% of the transverse excitation threshold. The transverse steering current localizes the excitatory field induced by the longitudinal current to more discrete regions of the nerve trunk [5]. Activation of individual muscles or groups of muscles was determined by comparing the torque vectors in the dorsiflexion/plantarflexion vs. toe-in/toe-out plane and the dorsiflexion/plantarflexion vs. inversion/eversion plane to the vectors recorded by supramaximal stimulation of individual muscle nerves [3].

III. RESULTS

A. Torque Recruitment

In all three experiments electrode configurations were identified that produced independent activation of the muscles that plantarflex and dorsiflex the ankle. The maximum torques generated were comparable to those measured by selective supramaximal stimulation of individual muscle nerves [3], indicating that the net torque at the ankle joint could be controlled over the full physiological range.

In the example shown in Fig. 2 tripoles 0° and 90° produced independent activation of the medial gastrocnemius (MG) and lateral gastrocnemius/soleus (LG/SL) muscles, respectively, at currents less than 1000μA (compare Figs. 2a and 2b). At higher current amplitudes, stimulation with either tripole 0° or tripole 90° activated all three muscles. Tripoles 180° and 270° selectively activated the muscles that produce dorsiflexion torques at the ankle (e.g. tibialis anterior), and at higher currents the stimulus spread to activate the plantarflexor muscles (Figs. 2c and 2d).

B. Effect of Field Steering Current

The use of transverse field steering current improved the performance of the multiple contact nerve cuff electrode. The addition of field steering current reduced the threshold for activation as illustrated by the shift of the recruitment curves to the left in Fig. 2. Field steering current also created a greater degree of selectivity between adjacent fascicles within the nerve trunk. This is illustrated in Figs. 2a and 2b by the increased separation between the recruitment of the MG and LG/SL. Finally, field steering current increased the dynamic range of torque recruitment and thus increased the value of the maximum torque that could be recruited before activation spread to antagonist muscles. This is indicated by the arrow in Fig. 2c and can be seen at the higher force levels in Figs. 2a and 2b.

IV. CONCLUSIONS

The results support our hypothesis that a single multiple contact nerve cuff electrode, placed on the sciatic nerve without prior reference to nerve fascicle location, is effective in controlling selectively and progressively the magnitude and direction of the torque at the ankle joint. The results also demonstrate the utility of recording joint torque, a variable directly associated with limb movement, rather than the forces from a select subset of muscles. Transverse field steering current reduced thresholds, increased the dynamic range of torque production, and allowed selective activation of more discrete regions of the nerve trunk.

REFERENCES

[1] Crago, P.E., P.H. Peckham, and G.B. Thrope (1980) Modulation of muscle force by recruitment during intramuscular stimulation. IEEE Trans. Biomed. Eng. 27:679-684.

[2] Glenn, W.W.L., and M.L. Phelps (1985) Diaphragm pacing by electrical stimulation of the phrenic nerve. Neurosurg. 17:974-984.

[3] Lawrence, J.H., T.R. Nichols, and A.W. English (1993) Cat hindlimb muscles exert substantial torques outside the sagittal plane. J. Neurophys. 62:282-285.

[4] Waters, R.L., D.R. McNeal, W. Faloon, and B. Clifford (1985) Functional electrical stimulation of the peroneal nerve for hemiplegia. J. Bone. Jnt. Surg. 67-A:792-793.

[5] Veraart, C., W.M. Grill, and J.T. Mortimer (1993) Selective control of muscle activation with a multipolar nerve cuff electrode. IEEE Trans. Biomed. Eng., in press.

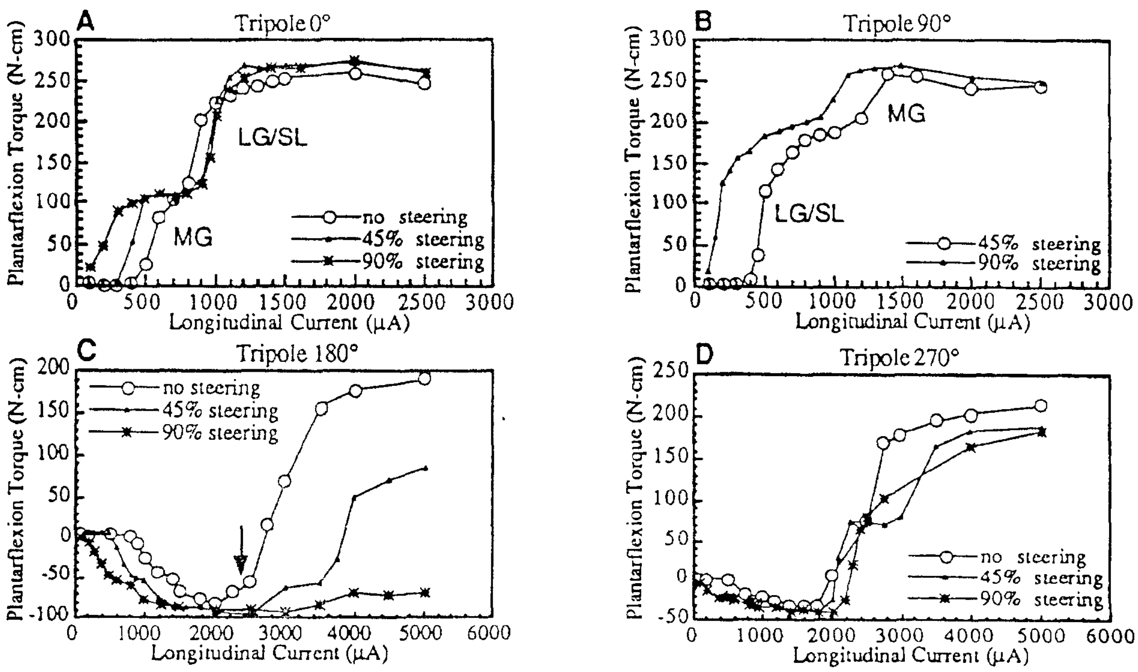

Figure 2: Ankle joint torque as a function of longitudinal stimulus current with different transverse steering current magnitudes.