Proceedings of the 1st International IEEE EMBS
Conference on Neural Engineering
Capri Island, Italy • March 20-22, 2003

Selective Stimulation on Nerve Fibers by Using High-frequency Blocking Technique

Chih-Wei Peng[1], Jia-Jin Jason Chen[1], Chou-Ching K. Lin[2]

[1] Institute of Biomedical Engineering, National Cheng Kung University, Tainan, Taiwan
[2] Department of Neurology, National Cheng Kung University Hospital, Tainan, Taiwan.

Abstract- **Traditional neural stimulation method recruits the muscle nerves in a reverse order of physiologic manner, i.e., can not recruit small diameter nerve fibers without recruiting large diameter ones. However, high frequency blocking technique is a feasible method for achieving selective stimulation and blocking nerve fibers. The aim of the study is to establish an animal model for studying order recruitment by using high frequency blocking investigation. In this study, a nerve cuff electrode was mounted on sciatic nerve with which two channel of stimulus was delivered for stimulation as well as for high frequency blocking investigation. Furthermore, a torque measurement systemwas established for assessing the stimulation or blocking performance in this study. Our results shows that variedlevels of blocking current can produce gradual change in the blocking effect from 8 % of residual torque to more than 90 % of maximal torque output. In muscle fatigue test, our results proved that high frequency blocking technique could achieve selective stimulation of smaller nerve fibers and blocking of larger fibers.**

Keywords - **High frequency blocking, sciatic nerve, nerve cuff electrode**

I. INTRODUCTION

An injury to the central nerve system (CNS) lesion, e.g., spinal cord injury and stroke, can cause permanent loss of voluntary motor and sensation functions. Selective stimulation on peripheral nerves is essential to restore of some motor or neuromodulation functions [1], e.g. the functional movement and bladder control. In additional to restore function of neurologically impaired individuals, the techniques of electrical stimulation have been used as a tool to study the mechanismand function of the neural system [2].

Because the peripheral nerve trunk mixes the sensory nerve fibers with the motor nerve fibers in a complex anatomic layout, it is rather difficult to selective stimulation on peripheral nerve via conventionally electrical stimulation techniques. The fiber diameter selectivity of electrical stimulation refers to the ability to stimulate nerve fibers within a range of diameters without stimulating nerve fibers having diameters outside that range. It is feasible to achieve selective stimulation via the modulation of stimulation parameters [3]. The principle is based on the discrepancy in the stimulation and blocking threshold of nerve fibers varied at fiber diameter sizes. Attempts have been made to achieve the recruitment order according to size principle by using the nerve stimulation and blocking technique [4].

Several blocking techniques, including anodal blocking, collision blocking, and high frequency blocking, with varied modulation of stimulus waveform have been developed. Anodal blocking requires large amplitude of monophasic current which might produce irreversible processes at the electrodes and lead to electrode corrosion [5]. Compared to large injection current used in anodic blocking, the high frequency blocking inhibits the muscle from contraction just at a suprathreshold level [6]. Additionally, the waveform applied to selective blocking can be monophasic or biphasic waveform. Therefore, high frequency blocking is less likely to cause nerve tissue damage or electrode corrosion in comparison with anodic blocking.

In this study, our aim is to establish selective nerve stimulation and blocking techniques as a basis for studying selective stimulation for various sizes of muscle fibers. At first an animal model using New Zealand white rabbit was established for high frequency blocking studies. A series of experiments were designed to verify the effects of selective stimulation and blocking in varied fiber diameter during a muscle fatiguing process.

II. METHODOLOGY

A. Experimental System

The acute animal experiment for electrical stimulation or blocking studies was performed on male of New Zealand white rabbits between 2.0 to 3.0 kg. All animals were anaesthetized with ketamine hydrochloride via intravenous injection on the ear (3 mg/ kg/ min., i.v.). A sterile technique was used to incise on the lateral side of the right hindleg from midthigh to popliteal fossa We transected the peroneal nerve in each animal and mounted the nerve cuff electrodes on the sciatic nerve such that the subsequent electrical stimulation on sciatic nerve can only activate plantar-flexor.

The blockdiagram of experimental setup used for blocking effects study is depicted in Fig. 1. The blocking and stimulation patterns were generated via D/A converter (PCI-6711, National Instruments Co.) and were delivered by two channels of stimulators to the nerve cuff electrodes placed on sciatic nerve. The generated isometric torque under different stimuli was measured with a 3-D force and moment transducer (US25-25, ATI, USA). The responsive torque was sampled at 500 Hz via an A/D converter (PCI-6034E, National Instruments Co.) with a graphics user interface controller written in LabView.

B. Experimental Protocol

1) Effects of Blocking Stimulation: To test the blocking effect, the monophasic rectangular blocking stimulus with 600Hz and 100 uS pulse width were applied in sciatic nerve of rabbit. Under the high frequency blocking scheme, we

delivered driving stimulus to produce tetanic contraction for a period of 5 second. During the stimulation duration, we simultaneously delivered the blocking stimulus to reduce the tetanic torque between 1 and 3 sec. The blocking effect (BE) can then be defined as the percentage of the maximal possible isometric torque reduced after a period of 2s of the given blocking condition.

2) *Verification of Selective Stimulation on Fiber Diameters:* In order to confirm that the high frequency blocking technique can recruit nerve fiber diameters from small one. We hypnotize that the fatiguing process during stimulating large nerve fibers should be different from that by stimulating small fibers, which can be able observed from the difference in decay of muscle force. Therefore, we wish to compare the muscle fatigue process by simply continuous with that with blocking stimulation at the same modulation force output. We first used use driving stimulus to recruit 50 % of maximal force for continuous 30 seconds to reach a nearly fatigue status. In contrast to driving stimulus, we utilized high frequency blocking technique to modulate 50 % of maximal force which was lasting for 30 seconds. We recorded the isometric torque during both tests from which we can observe the decay of muscle force from two different recruitment schemes at a same 50 % recruitment level. We used muscle fatigue test to gauge the performance of selectivity of nerve fiber diameters.

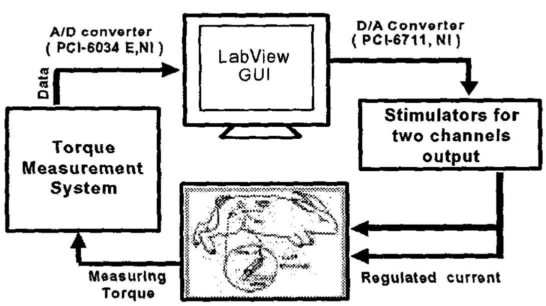

Figure 1. Configuration of experimental setup.

III. RESULTS

A. Pattern of Response Torque in Blocking Trials and Blocking Effect

Fig. 2 shows the torque measurements during varied amplitudes of 600-Hz monophasic rectangular blocking stimulus. We can the torque remained at a very low level before and after driving stimulation. During the first second of initial driving, the muscle force maintained a relatively stable torque output. The superimposition of a 600-Hz blocking stimulus to the sciatic nerve would not cause sudden drop in torque but a slow decline during the block stimulus. After cessation of the blocking stimulus, the background of tetanic torque returned, but on occasion not entirely to the original level. During the blocking period, some small residual torque always remained in all trials. Besides, a transient rising in the torque obviously appeared when the blocking stimulus was in higher blocking current.

Fig. 3 shows the blocking effects at varied blocking current amplitudes. At lower blocking current, the blocking effect was not evident. The blocking effect was around 10 % at 0.25 mA blocking intensity. After that the blocking effects increase gradually until a maximum limit was reached, around 91.2 % blocking effect at 0.8 mA in this case. After reaching the maximum, the blocking effect was kept relatively constant, disregarding the increase of blocking intensity.

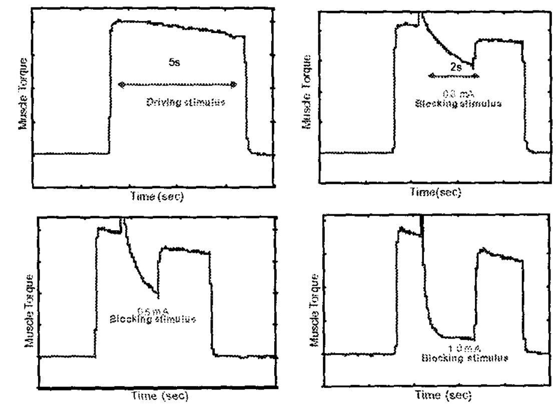

Figure 2. Attenuation in torque under varied levels of blocking stimulus during a 5 sec of stimulation.

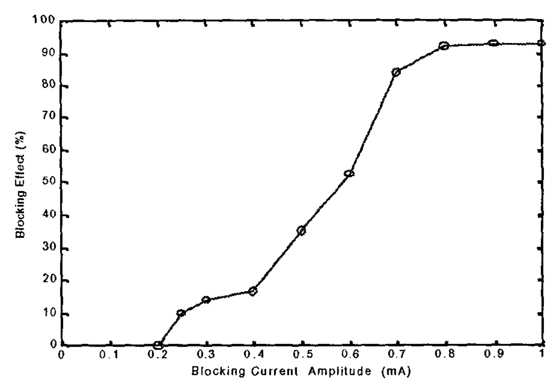

Figure 3. Blocking effect of varied levels of blocking current resembles to sigmoid curve.

C. Effects of Selectivity in Fiber Diameters

Figure 4 depicts the decreasing trends of the measured torques during the fatigue process of 50 % driving stimulus and 50 % blocking effect. We can clearly observe that the normalized torques of driving stimulus decreased at a faster rate, compared to those of high frequency blocking. Therefore, these results reveal that the driving stimulus presumably activates more large-diameter nerve fibers (fast muscle units), so the muscle fatigue in a faster rate. In contrast to driving stimulus, high frequency blocking activates mainly small-diameter nerve fibers (slow muscle units). From the muscle fatigue test by using stimulation and blocking schemes, we have demonstrated that high frequency blocking activates nerve fibers mainly from small diameter to large diameter, which is different from that of driving stimulus.

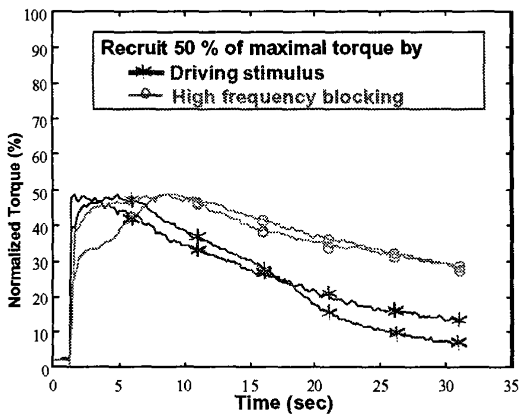

Figure 4. Decay of normalized torque during muscle fatigue process caused by driving stimulus (-o-) and high frequency blocking (-*-)

IV. DISCUSSION and CONCLUSION

Our results show that varied levels of blocking current can produce gradual change in the blocking effect. The curve of blocking effects closely resemble to a sigmoid curve. The blocking effect is rather small below a threshold and increases to about 90 percent of the maximal torque. In addition, there are always some residual torques, about 8 % of the maximal tetanic torque, during the blocking period.

The utilization of high frequency blocking technique for achieving recruitment of muscle fibers in a physiological recruitment order has been demonstrated. This has been shown from the reactive torque resulted from 50 % blocking stimulus decayed slowly than that with 50 % driving stimulus. These results suggest that slow-twitch, fatigue-resistant muscle units could be activated first via high frequency blocking. Therefore, it indirectly demonstrates that the technique can achieve selective stimulation nerve fibers mainly from small diameter to large diameter. By modulating the amplitude of blocking stimulus, selective stimulation on the size of muscle fibers can be achieved.

In this study, we have accomplished the setup of experimental system for acute animal studies of selective stimulation and blocking, including stimulation system, animal model, torque measurement system, nerve cuff electrodes, and recording system. We have demonstrated the feasibility to perform selectively stimulation by using high frequency blocking techniques. However, the mechanism of high frequency blocking has not been fully investigated. It is believed that additional neurophysiological information can be acquired from the stimulus EMG during muscle fatigue process. Furthermore, the chronic effects of high frequency blocking by using long-term implanted device needs further investigation. In addition, the ultimate goal is to evaluate the feasibility of applying the selective blocking techniques for human studies, especially for the investigations of spastic suppression, bladder control, and pain relief.

ACKNOWLEDGMENT

This work was partially supported by the National Health Research Institute, under grants NHRI-EX90-9017EP, and the National Science Council (NSC91-2213-E-006-061), Taiwan, ROC.

REFERENCES

[1] R. B. Stein, P. H. Peckham, D. B. Popovic, Neural Prostheses: Replacing Motor Function after Disease or Disability, Oxford University Press, New York, 1992.

[2] A. Kralj, T. Bajd, R. Turk, et al., "Gait restoration in paraplegic patients: a feasibility demonstration using multichannel surface electrode FES," *J. Rehabilitation R&D,* vol. 20, pp. 3-20, 1983

[3] W. M. Grill, J. T. Mortimer, "Stimulus waveforms for selective neural stimulation," *IEEE Trans. Biomed. Eng.*, vol. 42, pp. 168-74, 1995.

[4] Z. P. Fang, J. T. Mortimer, "Selective activation of small motor axons by quasitrapezoidal current pulses," *IEEE Trans. Biomed. Eng.*, vol. 38, pp.168-74, 1991.

[5] L. S. Robblee, T. L. Rose, "Electrochemical guidelines for selection of protocols and electrode materials for neural stimulation," Neural Prostheses: Fundamental Studies. Prentice Hall, New Jersey, 1990.

[6] R. Baratta, M. Ichue, S. K. Hwang, et al., "Orderly stimulation of skeletal muscle motor units with tripolar nerve cuff electrode," *IEEE Trans. Biomed. Eng.*, vol. 36, pp. 836-43, 1989.

[7] M. Solomonow, "External control of the neuromuscular system," *IEEE Trans. Biomed. Eng.*, vol. 31, pp. 752-63, 1984.