

CLOSED-LOOP FES FOR RESTORATION OF GAIT FUNCTION IN PATIENTS WITH FOOT DROP

Seung Kwan Lim¹, Ho Choon Jeong¹, Sang Se Lee¹
Dal Bok Jin¹, Moon Yong Lee², Byung Rim Park²

¹Faculty of Electronic Engineering, Wonkwang University Graduate School
²Department of Physiology, Wonkwang University School of Medicine

Iksan 570-749, Korea

ABSTRACT

A portable and convenient closed-loop controlled electrical stimulator has been developed for patients with foot drop caused by CNS injury. The system was composed of optical sensor for detecting joint angle, programmed stimulator for FES and TES, and surface electrodes. Stimulus intensity was controlled automatically to maintain the programmed level of the ankle joint angle after detecting the changes of degree of ankle joint during walking. Also the stimulus intensity which was affected by increased electrode impedance resulting from long time use was controlled automatically. The joint angle was detected by an optical sensor and the stimulus intensity was adjusted by modified PID control if the joint angle deviated from the preset value. Stimulus parameters were 30~80 volt, 40 Hz, and 0.2 ms. Electrical stimulation was applied to the common peroneal nerve through surface electrodes in 5 hemiparetic patients caused by stroke. Gait function including velocity was restored by the system, and muscle force was increased by TES. The system restored gait function as well as prevented from muscle atrophy of lower limb in hemiparetic patients.

Key words: foot drop, closed-loop FES, hemiparesis

INTRODUCTION

In recent years there has been increasing interest in the utilization of functional electrical stimulation (FES) for restoring motor function in the paralyzed extremities caused by central motor neuron disorders.¹⁾ Portable systems have been used for restoration of gait function in patients with foot drop caused by stroke, which are controlled by open-loop system. The open-loop controlled system has less effective for preventing foot drop since electrode impedance and muscle fatigue increase by stimulation for long time. Therefore, stimulus intensity should be increased in proportion to increased impedance and fatigue in order to prevent from foot drop during walking. In this study FES controlled by closed-loop system with surface electrode was developed and the effect of the closed-loop controlled system on gait function was evaluated in hemiparetic patients.

METHODS

Closed-loop controlled system is composed of microprocessor, high voltage generator, surface electrode, and display. Period of stimulation is determined by detection of swing and stance phases by pressure sensor, and ankle joint angle is identified by optical sensor. Ankle joint angle is controlled by stimulus intensity which is regulated by D/A converter in PID system. The output signal from microcontroller is applied to the common peroneal nerve through surface electrode in order to prevent from foot drop. Eight healthy adults (5 male and 3 female; average age 29.7 ys) and 5 hemiparetic patients were examined. To determine an optimal stimulus parameter electrical stimulations with pulse width modulation at range of 0.1 - 0.5 ms and with frequency modulation at range of 20 - 50 Hz were applied to the common peroneal nerve through surface electrodes in healthy subject. In hemiparesis patients electrical

stimulation with 0.2 ms, 40 Hz was applied to the common peroneal nerve for 40 days.

RESULTS

1. Optimal parameter of electrical stimulation

To determine the optimal pulse width at frequency of 40 Hz, moment at ankle joint was measured for 100 sec when electrical stimulation with pulse width of 0.1 - 0.5 ms was applied to the common peroneal nerve through surface electrode in healthy subjects. Electrical stimulation at 0.2 ms produced relatively strong tension among other pulse widths. When electrical stimulation with frequency of 20 - 50 Hz at 0.2 ms was applied to the common peroneal nerve for 100 sec, 40 Hz maintained relatively strong tension. Therefore, optimal parameter for electrical stimulation was determined as pulse width of 0.2 ms and frequency of 40 Hz in this study (Fig. 1).

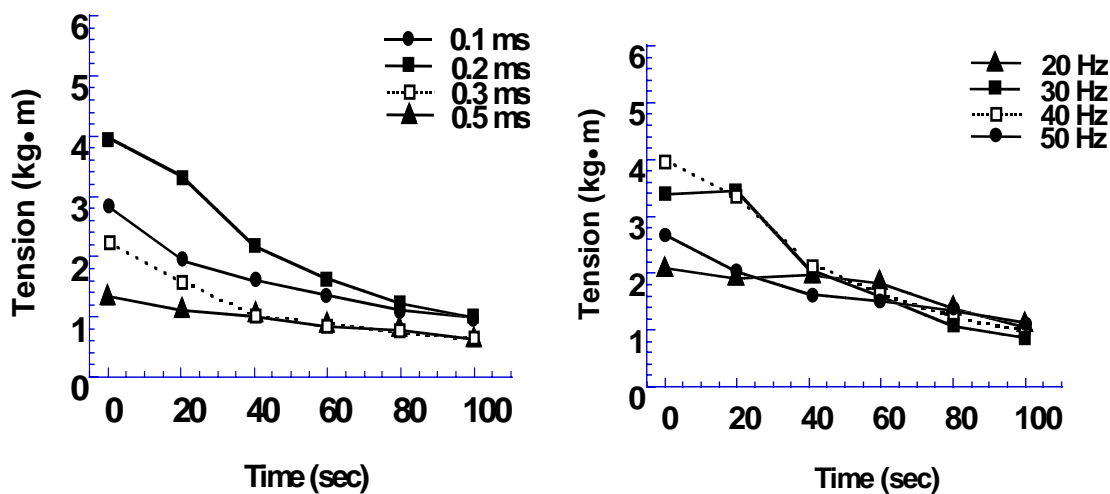


Fig. 1. Time-dependent changes on tension of ankle dorsiflexors by stimulation of the common peroneal nerve in healthy subjects.

2. Modulation of stimulus intensity resulting from change of the ankle joint angle

In open-loop controlled system, stimulus intensity was sustained constantly even though the joint angle was changed at range of 0 to 60 degrees. However, closed-loop controlled system modulated stimulus intensity automatically depending on changes of the joint angle by PID program. Stimulus intensity was more increased to maintain the preset level when the joint angle was far from the preset level, and the intensity was decreased if the joint angle was close to the preset level.

3. Effect of electrical stimulation on moment of the ankle joint

The moment by TES in 5 hemiparetic patients was increased gradually with time, especially the effect was more prominent in younger patient group. The muscle force was increased up to 29.7% 6 weeks after stimulation in 5 patients. Also, muscle fatigue was decreased compared with the level before stimulation. When the closed-loop controlled system was applied to the patients, gait function was improved (Fig. 2).

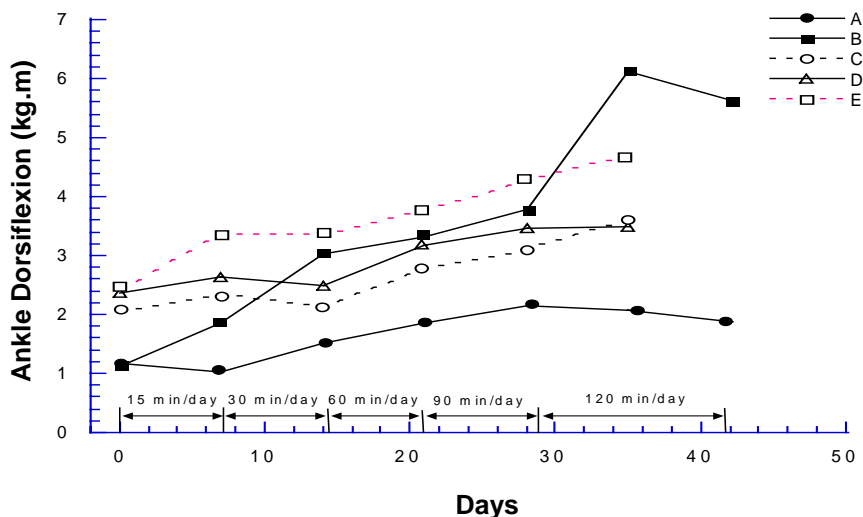


Fig. 2. Time-dependent changes on tension of ankle dorsiflexors by TES in 5 hemiparetic patients.

DISCUSSION

The optimal parameter for electrical stimulation was reported that 0.2 ms, 20 Hz in slow muscles and 0.3 ms, 40 Hz in fast muscles.²⁾ Considering the muscles for ankle dorsiflexion were composed of slow and fast muscles, 0.2 ms and 40 Hz would be acceptable as an optimal stimulus parameter of the common peroneal nerve through surface electrodes. Open-loop controlled FES has several problems, such as the patients can not control their gait velocity and joint angle when the degree of ankle dorsiflexion is decreased due to increased impedance of electrodes. But closed-loop controlled FES including PID, pressure sensor and optical sensor can modulate gait velocity and stimulus intensity to maintain the preset level of the joint angle. Chronic electrical stimulation of the paralyzed muscles increased muscle force and decreased muscle fatigue gradually with time. These improvements by electrical stimulation may result from electrical effect, which increases metabolism by changing from anaerobic into aerobic metabolism, increasing blood flow, oxygen consumption, and glucose consumption. Especially, decrease of muscle fatigue by electrical stimulation results from decreased production of lactic acid in addition to the previous explanations.³⁾ (Supported by ITEP 1996)

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