Effect of intensive functional electrical stimulation therapy on the upper limb motor recovery after stroke: Single case study of a chronic stroke patient
Noritaka Kawashima1,2,3, PhD, Milos R Popovic1,2, PhD, and Vera Zivanovic2, MD
1 Institute of Biomaterials and Biomedical Engineering, University of Toronto
2 Lyndhurst Centre, Toronto Rehab
3 Japanese Society for Promotion of Science

Abstract
This case report describes a stroke patient who participated in an intensive functional electrical stimulation (FES) therapy that consisted of task-specific upper arm movements with a combination of pre-programmed electrical stimulation and manually assisted motion. The patient was a 22-year-old woman who had suffered a hemorrhagic stroke 2 years earlier. Motor function of the upper extremity was severely impaired and showed the typical flexor synergy pattern. The FES therapy was carried out for 12 weeks, two times per day, one hour in each session (108 training sessions in total). The patient showed remarkable improvement in the coordination of the shoulder and elbow joints during the kinematic test. While the motor recovery (measured using the Chedoke McMaster Stroke Assessment (CMSA) scale and maximal voluntary contraction level of upper arm muscles) did not show any remarkable changes, there was remarkable reduction of the arm spasticity and muscle tone; observed was a decrease in the Modified Ashworth Scale (MAS) and a reduction of the H-reflex in the wrist flexor muscle. The present results suggest that intensive FES therapy has the capability of improving upper limb function in chronic stroke patients. The improvement of the upper limb motion can be attributed to the enhancement of coordinated muscle activation patterns and the reduction of spasticity and muscle tone.

1 Introduction
Functional electrical stimulation (FES) therapy is a treatment that integrates electrical stimulation of sensory motor systems and the repetitive functional movement of the paretic arm in hemiplegic or quadriplegic patients [5,9]. In FES therapy, a preprogrammed electrical stimulation, and manual support of joint motion by a therapist are used to help the patient achieve functional arm motion. With this assistance, the patient feels that his/her paralyzed muscles are performing the desired contractions in a synergistic manner and are accomplishing the arm motion with appropriate effort. Simultaneously, sensory signals might be generated by the excitation ofafferent pathways in the stimulated peripheral nerves. Recent studies that used this novel therapeutic method reported significantly better recovery of upper extremity functions, especially in acute stroke patients [4,5,8,9]. However, some important questions remain regarding the effectiveness of FES therapy, such as what is the neural mechanism underlying an improvement of the sensorimotor function, and whether this therapy is effective for chronic stroke patients.

It is well known that most of the sensorimotor recovery occurs during the first four weeks after a stroke and that it is not easy to restore motor function in chronic stroke patients. However, the true potential for chronic stroke patients to improve their upper limb functions is still unknown. In the present study, we aimed at addressing the question of the extent of improvement in reaching and grasping functions, by the use of intensive FES therapy on chronic stroke patients. For this purpose, we conducted a single case study to examine the effects of intensive FES therapy on upper limb function in a severe chronic stroke patient. The FES therapy consisted of a variety of task-specific multi-joint movements with the combination of manually assisted passive motion.

2 Methods

2.1 Patient Description
The patient was a 22-year-old woman who had suffered an ischemic stroke in the right frontal parietal area two years prior to her participation in this study. While left leg showed good recovery, the left arm was not functional due to high tone. At the beginning of the FES therapy, the patient was independent in activities of daily living, but reported that she rarely used her paretic upper limb for functional activities.

2.2 Protocol

FES: Symmetrical biphasic current pulses with pulse duration of 250 microseconds were generated by the Compex Motion electric stimulator. The stimulation frequency was 40 Hz, and the therapist used a hand
switch to trigger stimulation when it was determined that the patient needed assistance with the task. The following muscles were stimulated with the surface stimulation electrodes (see Fig.1A): anterior deltoid (aDel), posterior deltoid (pDel), biceps brachialis (BB), triceps brachialis (TB), extensor carpi radialis longus and brevis, extensor carpi ulnaris, flexor carpi radialis and flexor carpi-ulnaris.

**FES Therapy protocol:** The patient was seated with both her arms relaxed in neutral position. The FES was delivered to shoulder and elbow extensor and flexor muscles while the patient performed specific types of motions: □ Touch nose, □ Touch shoulder, □ Move arm forward, □ Lift arm left side up, □ Grasping large object, □ Grasping a small object. The therapy consisted of 2 concurrent components: (1) pre-programmed coordinate muscular stimulation that coincided with the phase and type of arm motion; the stimulation amplitudes were 2 times greater than the motor threshold stimulations; and (2) manually assisted passive motion to establish physiologically correct movement. The FES therapy was carried out for an hour, twice a day. The patient was asked to repeat the same arm task 10 times for each motion during a single treatment session. The treatment sessions lasted up to 60 minutes.

### 2.3 Outcome Measures

To capture the FES therapy-induced improvements of the upper arm function, the following assessments were performed: (1) clinical assessments (Chedoke McMaster Stages of Motor Recovery (CMSMR), Motoricity Index, Maximum Voluntary Contraction (MVC), and Modified Ashworth Scale (MAS), (2) electrophysiological assessment (H-reflex), and (3) kinematical measurements (drawing test).

### 3 Results

While the CMSMR did not show any changes, the MAS of the hand and wrist showed reduction over the time course of the training (wrist: 3 to 2, hand: 4 to 3).

H-reflex, which reflects the spinal motoneuron excitability, also showed remarkable reduction with training (Fig.2). Fig.3 shows the changes in the MVC in the upper arm muscles obtained every two weeks. While there were no consistent changes of the MVC level among all muscles, some muscles showed meaningful changes with the time course of training, for example, the FDI and TB muscle, which did not show any EMG activity at the beginning of the FES therapy, showed a visible EMG as the result of the FES therapy, which patient was able to control voluntarily. Fig.4 shows the x-y plot of the shoulder, elbow, wrist, and index finger positions while the patient was performing circle drawing test. While the size of drawn circle by the index finger was small at the 6th week of the FES therapy, its size became larger as the therapy progressed.

### 4 Discussion

Although motor capacity score, i.e., CMSMR and MVC tests did not show any changes, the MAS and the amplitude of H-reflex were reduced as the result of the FES therapy. Additionally, the kinematic results...
showed a profound improvement in the ability to perform arm movements and to coordinate shoulder and elbow joints. These results suggest that the improvement of the upper arm functional motion can be attributed not only to motor recovery itself, but also to the reduction of muscle tone and/or spasticity. The muscle tone of wrist and elbow flexors was remarkably decreased as the result of the FES therapy, which was clearly reflected by the results of MAS and H-reflex (Fig.3). This result was in good agreement with the previous findings that describe the effects of the electrical stimulation on the reduction of the abnormally high muscle tone [2,3]. Therefore, the improvement of the upper arm functional motion can be partly attributed to the reduction of muscle tone and/or spasticity. This finding supports the classical concept that muscle tone reduction represents simplistic solutions to the deficit in motor control after stroke [7].

In the present study, we developed a pre-programmed stimulus patterns that are able to generate four upper limb movements/functions. The temporal activations of the muscles induced by the FES were similar to those of intact neuromuscular system that is performing the same task. Thus, during the movements the patient could feel when she was supposed to activate muscle contractions and how to sequence them to produce desired movements. The fact that we have observed marked changes in the H-reflex and that a number of muscles that the patient was unable to voluntarily contract prior to the FES therapy were under her voluntary control at the end of the therapy suggests that the functional improvements induced by the FES therapy are in part due to changes that occur in the central nervous system. We therefore speculate that the following mechanism causes the changes observed in this and our two prior studies[5,9]. If a hemiplegic patient who strains to execute a task is assisted with the FES to carry out that same task, he/she is effectively voluntarily generating the motor command (desire to move the arm, i.e., efferent motor command) and the FES is providing the afferent feedbacks (afferent sensory input), indicating that the command was executed successfully. We hypothesize that, by providing both the motor command and sensory input to the central nervous system repetitively for prolonged periods of time, this type of treatment facilitates functional reorganization and retraining of intact parts of the of central nervous system and allows them to take over the function of the damaged part of the central nervous system. As the patient continues to improve the voluntary function then the volitional-related sensory feedback from the stimulated muscles and arm [1] further contributes to this retraining process. In the future study, a randomized controlled trial will be needed to ascertain the effect of the FES therapy on the motor recovery of chronic, severe stroke patients.

5 References


Acknowledgement
This work was supported by Physician Services Incorporated, Toronto Rehabilitation Institute, Ontario Ministry of Health and Long-Term Care, and Natural Sciences and Engineering Research Council of Canada.