Restoration of Grasping Functions in Patients with Quadriplegia

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Introduction

In this study functional electrical stimulation (FES) was used with patients with complete and incomplete spinal cord injuries (SCI) in an effort to facilitate improved hand function. By improving a patient’s ability to grasp and release everyday objects we hoped to see increased independence in activities of daily living (ADL). It was anticipated that the application of daily FES training, in addition to regular occupational therapy (OT) and physiotherapy (PT), would facilitate the restoration of neurological function in the wrist or fingers. We were examining the carryover effect of using a neuroprosthesis for grasping in our patients. The results were compared to controls that received regular physiotherapy and occupational therapy which included electrical stimulation for muscle strengthening without the functional component. By doing this study we hoped to answer the following questions: What is the best way to apply FES to restore hand function and maximize functional independence?

1. Materials and Methods

1.1 Participants

Patients were either complete or incomplete SCI, ranging from C4 to C7. At admission to the study participants had no functional hand movement. They either had no voluntarily movement in their wrist and/or fingers, or may demonstrated flickers of movement up to grade 2-. The participants were recruited to the program within seven months of their date of injury.

Patients were randomly divided into two groups: Group A - patients that were trained with the neuroprosthesis; or Group B - the control group which received standard occupational therapy and physiotherapy without FES. To date seven patients have signed a letter of consent and have been recruited. Six were assigned to Group A and one to Group B. This study is in the preliminary stages and we plan to have 40 patients in total. This research received ethics approval from the University of Toronto and Toronto Rehabilitation Institute ethics boards in 2002.

1.2 Neuroprosthesis Hardware used in the Study

The Compex Motion electric stimulator, developed by Popovic and Keller in collaboration with Compex SA [1], was used as a hardware platform for the neuroprosthesis for grasping. This programmable FES system has four channels and applies surface stimulation technology and provides the means to develop custom-made neuroprostheses. In our study each patient had individualized stimulation protocol to facilitate grasping function. Stimulation was triggered by a push button which the patient controlled. The FES program evolved during the treatment and was adjusted according to patient’s progress, typically every two weeks.

1.3 Stimulation Protocols used in the Study

The neuroprosthesis treatment consisted of a strengthening phase followed by a functional training phase. The strengthening phase was required in the early stages of the program for patients who demonstrated a very weak and inefficient response to FES. This period often lasted a few weeks. Once a sufficient response was achieved functional training began and the patient was asked to grasp and release everyday objects, such as a can of pop, using the neuroprosthesis. The participant repeated the same hand task 30 to 50 times during a 60-minute treatment session. Patients had one or two treatment sessions per day, five days per week. During the
intervention, the OT adjusted the placement of electrodes and guided the hand movements. The OT ensured that all movements were functional, efficient and used normal movement patterns. An independent hand strengthening and stretching program was provided as needed to facilitate normal hand function.

Self-adhesive surface stimulation electrodes were applied above the following muscles and nerves: 1) flexor digitorum superficialis m. and the flexor digitorum profundus m.; 2) median nerve, flexor pollicis brevis and opponens pollicis m.; 3) extensor digitorum m.; 4) radial nerve, extensor carpi radialis longus and brevis, m. and extensor carpi ulnaris m. Stimulation parameters used were: 1) balanced, biphasic, current regulated electrical pulses; 2) pulse amplitude from 8 to 50 mA (typical values 17-26mA); 3) pulse width 250 µs; and 4) pulse frequency from 20 to 70 Hz (typical value 40 Hz).

As soon as the patient showed signs of recovery of the either voluntary extension or flexion in a muscle group they were encouraged to make an effort in producing the movements voluntarily, which were previously facilitated by the FES. The stimulation protocol promoted occasional wrist extension with the desired finger extension. Since the majority of patients with quadriplegia demonstrate upper extremity paralysis with spasticity in the finger flexors, the occasional wrist extension caused by the stimulation did not disrupt the tenodesis function. During the treatment period patients were observed to have a decrease in spasticity in the fingers allowing better control of finger flexion and extension.

1.4 Tests

Assessments were conducted on all seven subjects.

Administrative test: demographic information and participants’ medical history was collected at admission

Functional tests: Conducted pre and post injury: 1) Functional Independence Measure (FIM); 2) Spinal Cord Independence Measure (SCIM); 3) Passive and active range of motion; 4) Manual muscle testing; 5) Grip and pinch strength using dynamometers; 6) Nine hole peg test; 7) Rehabilitation Engineering Laboratory Hand Function Test for Functional Electrical Stimulation Assisted Grasping (REL)[2]; and 8) A writing sample.

Qualitative interview: interviews conducted with an independent assessor to explore patients’ experience with FES and their perceptions of its impact on daily functioning.

2. Results

Group A:

Patient No. 1: 58-year-old male patient with C5-6 motor complete quadriplegia began the FES program approximately six months post-injury with a weak wrist extension and no active finger movements in right arm. After three months of daily treatments he was able to use a tenodesis grasp functionally due to increased wrist extension strength. He also demonstrated flickers of movement in individual finger extension. Functionally, the patient was able to grasp and release various objects such as grapes and popcorn without use of the neuroprosthesis.

Patient No. 2: 18-year-old male with C7 incomplete quadriplegia. Admitted to FES program one month post injury. Presented with grade 4 wrist extension, flickers of finger flexion/extension and thumb flexion and abduction. Used tenodesis for grasp. After 2.5 months of FES training: 1) grade 3-4 voluntary flexion, extension of all digits; 2) right hand was stronger in finger flexion and left hand was stronger in finger extension; and 3) fully independent in ADL.

Patient No. 3: 19-year-old male patient with C6 incomplete quadriplegia started FES treatment two months after onset of SCI. At admission he only demonstrated a weak left tenodesis grasp and was fully dependent in ADL. After three months of neuroprosthesis treatment he demonstrated: 1) voluntary finger flexion, opposition and finger extension in left arm; 2) used a power grasp voluntarily to grasp and release objects; and 3) complete independence in ADL.

Patient No. 4: 24-year-old male diagnosed with C4 complete quadriplegia started FES treatment three months post injury. Following two months of treatment he was able to flex his left elbow against gravity in order to assist with eating, drinking and brushing his teeth while using a universal cuff. While wearing the
neuroprosthesis he was able to place his left hand around small objects and raise them to mouth level. No neurological recovery was observed in the left wrist or fingers.

**Patients who were not yet discharged from the FES program at the time this article was written:**

**Patient No. 5:** 63-year-old male with central cord syndrome (C4 incomplete quadriplegia) admitted to the FES program one month post injury. He was fully dependent in ADL and demonstrated no functional grasp, very weak (2-) finger flexion, extension and thumb flexion/abduction bilaterally. After a month of FES training the following recovery was observed in both arms: 1) grade 4 finger flexion/extension, and thumb opposition in right hand enabling a power grasp and fine motor control; 2) left hand was weaker than the right, patient was able to manage gross motor activities with left hand; and 3) increased independence in self-care.

**Patient No. 6:** 22-year-old male with C5 complete quadriplegia. FES was initiated three months after injury once patient demonstrated a flicker of right wrist extension. The goal of the FES was to increase strength and develop a tenodesis grasp. After 2 months of FES training: 1) increase strength in wrist extension to grade 2-; and 2) able to use the neuroprosthesis independently to grasp and release objects, unable to grasp without the neuroprosthesis.

The results can be summarized into five points: 1) following the initial sessions with FES patients appeared motivated to continue participating in the program; 2) objective increases in hand flexibility, strength and dexterity were observed following FES; 3) decreased spasticity further facilitated independent grasping abilities; 4) post FES treatment patients increased their level of independence in ADL; and 5) the result of the qualitative interviews indicated four main themes: patients reported increases in hand function, greater independence in activities of daily living, a sense of satisfaction, and reported long term commitment to the technology to facilitate recovery. It should be noted that patients without large functional changes in independent muscle activity could use the neuroprosthesis for functional tasks. In Figures 1 and 2 assessment scores obtained for patients 1 through 4 are presented.

**Group B:**

**Patient No. 7:** 46-year-old, male patient with C6 complete quadriplegia started standard OT and PT treatments in a rehabilitation centre seven months after onset of SCI. After another two months of standard therapy his hand function remained unchanged.

3. Discussion

The study presented suggests that a treatment consisting of repetitive execution of the grasping tasks assisted with FES, promotes recovery of grasping function in both complete and incomplete SCI patients. However, the recovery in incomplete SCI patients is significantly greater compared to complete SCI patients. This result suggests that FES may cause reorganisation in the central nervous system after SCI, and that it promotes function recovery.

Currently we are in the preliminary stages of this study. Our objective is to have 40 participants (20 intervention, 20 controls). As the evidence for FES is building our goal is to apply the findings to daily occupational therapy practice. The results of our research to date indicate the following practices are useful to maximizing recovery: 1) individualized stimulation programs that are monitored and adjusted by an OT; 2) a strengthening program followed by functional training increases likelihood of carryover; 3) FES is best complimented with regular PT and OT which includes hand stretching and strengthening; and 4) FES treatment is an excellent therapy that can be applied for a short period of time and can facilitate durable results in maximizing grasping function and increasing independent living skills.

References:


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Figure 1: Average REL test results for Group A before and after the treatment
Figure 2: Average FIM and SCIM test results for Group A before and after the treatment