

# Early FES Intervention for the Restoration of Ambulatory Function in Persons with Incomplete Spinal Cord Injury

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## **Abstract**

*FES can be of benefit in the treatment of the patient with incomplete spinal cord injury. A series of 12 subjects who received FES intervention in the immediate post injury phase demonstrated significantly improved motor scores in that average improvement in the most affected weaker limb was 200% (range 128-443%). FES can assist three principal goals of rehabilitation-muscle strengthening & endurance, motor recovery and early gait re-training. Reduction of the effects of disuse muscle atrophy that is common after SCI and early gait re-education may be two of the principal benefits of early FES intervention. Chronic gait deficits, in particular difficulty with swing phase of gait, may also be minimized with early common peroneal nerve stimulation for the restoration of active dorsiflexion and hip flexion. Functional outcomes, particularly ambulatory capacity, in ASIA C and D patients can be improved with early FES intervention.*

## **1. INTRODUCTION**

Restoration of independent ambulation in the incomplete spinal cord injury (ISCI) patient is generally a primary goal of rehabilitation. Improvement of motor function and endurance in muscles affected by the SCI is key to the attainment of a functional gait. Various studies<sup>1,2</sup> have highlighted the correlation between early recovery of lower extremity motor function and ability to ambulate following ISCI. Functional electrical stimulation is recognised as a means of enhancing gait in ISCI. For instance, it has been demonstrated in ISCI & stroke patients that stimulation applied to the common peroneal nerve of the affected leg enhances limb swing and foot clearance during the swing phase of gait<sup>3</sup>. However, FES intervention to enhance walking speed and endurance is applied as a means of correcting gait abnormalities, generally at a later phase of rehabilitation when chronic gait deficits have developed. This strategy, however, may have limited benefit for

the ISCI patient months or years post injury as there may be chronic weakness and loss of endurance in major muscle groups responsible for walking. Disuse atrophy is cited as one of the contributing factors in muscle weakness and decreased development of muscle force after SCI. It is thought to occur from loss of muscle activation due to disruption of central and segmental synaptic drive into surviving spinal motoneurons.<sup>4</sup> The benefit of early FES intervention after ISCI may be that disuse atrophy in muscles affected by the SCI is, to some degree, arrested. This may lead to improved ambulatory outcomes.

## **2. METHODS**

### **2.1 Objectives**

1. To describe a protocol of early FES intervention for the enhancement of motor function in individuals with ISCI. 2. To document changes in lower extremity motor scores (LEMS) in subjects who received early FES protocol.

### **2.2 Study Design**

Retrospective study of changes in lower extremity motor scores in a group of twelve individuals with ISCI (7 cervical, 5 thoracic) who received early, extensive FES as part of their rehabilitation on admission to a tertiary rehabilitation facility.

All subjects were assessed as per the American Spinal Injury Association (ASIA) classification of spinal cord injury<sup>5</sup>, a validated objective measure of neurologic status after spinal cord injury. Admission and discharge ASIA motor scores (strength of 5 key muscles per limb graded at 0 to 5 muscle strength, maximum score per limb = 25). ASIA impairment scale (C or D) and ambulatory capacity were evaluated on initial and final assessment.

### **2.3 Subjects**

12 subjects with a diagnosis of ISCI, 8 presented with unilateral lower limb weakness in that they preserved close to normal motor scores on their less affected limb (LAL). 4 presented with bilateral weakness in that their LAL motor score was only marginally higher

than their most affected limb (MAL). Strength of key muscles: hip flexors (L2), knee extensors (L3), ankle dorsiflexors (L4), long toe extensors (L5) and ankle plantarflexors (S1) was assessed pre and post treatment. Presentation of neurologic deficit was according to the ASIA impairment scale. 6 subjects were classified as ASIA C [motor function is preserved below the neurological level, and the majority of key muscles below the neurological level have a muscle grade less than 3}. 6 subjects were classified as ASIA D {majority of key muscles have a muscle grade greater than or equal to 3}. None of the subjects could stand or walk on initial assessment.

### 2.3 Intervention

The goals of FES application were 1) recovery of motor function. 2) improvement of strength & endurance 3) gait re-training.

**Motor Recovery:** In muscles demonstrating flickers (grade 1 muscle activity) a program of therapeutic FES was applied. This included unilateral or bilateral stimulation of quadriceps, hamstrings and glutei muscles. As voluntary motor recovery was observed in the stimulated muscles (grade 2, or better muscle activity) a regimen of muscle strengthening and conditioning was commenced. This included weight resistance training and development of anti-gravity strength in the targeted muscle groups.

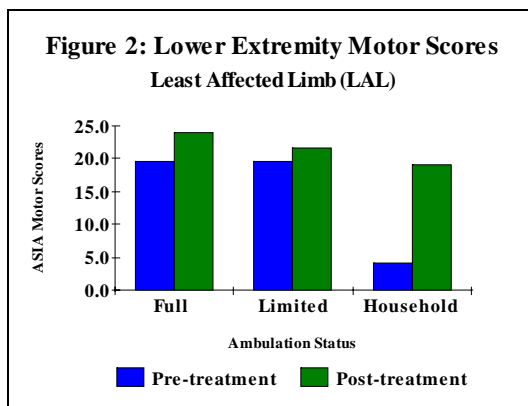
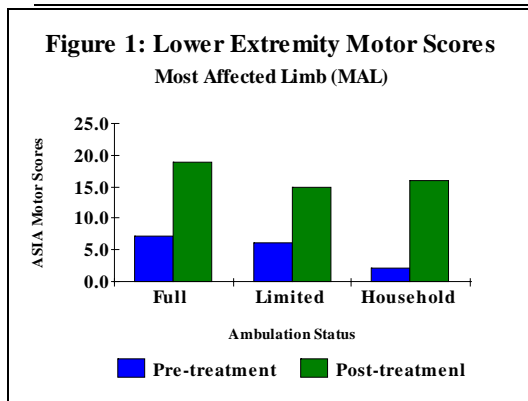
**Strength & Endurance Training:** Retraining of the flexion withdrawal response of one or both lower limbs was commenced with stimulation of the common peroneal nerve. The active electrode was placed behind the head of the fibula, the indifferent over the tibialis anterior muscle. The limb to be stimulated was positioned with the hip and knee at 90 ° to allow dorsiflexion through range at the ankle. Stimulation was applied for an average of 1 hour per day (duty cycle- 5 seconds on/4 off; 35 pulses per second) producing dorsiflexion through range and was continued until the patient could actively dorsiflex the ankle. (Average duration of 2 months). As voluntary activity was observed in the anterior tibial muscles, proprioceptive input was provided with stimulation to re-train a flexion response at the hip, knee and ankle. As subjects regained anti-gravity power in the limb flexors they were progressed to a weight resistance training regimen of extensor muscle groups required for independent standing and erect posture.

**Gait Re-training:** Once subjects were able to stand independently, either in the parallel bars or using a walker, the WalkAide 2 common peroneal foot drop stimulator was fitted to

promote early stepping activity and facilitate the swing phase of gait. The triple flexion response, obtained with CPN stimulation elicits a flexion moment at the hip and knee and ankle. Balanced ankle dorsiflexion through activation of the tibialis anterior and peronei muscles facilitates heel contact on initial stance. A gait pattern, customised for the individual, and programmed using a hand or foot-switch trigger was set up. Subsequently, as walking ability and endurance increased with FES assistance, a tilt-sensor walk was programmed with the WalkAide 2 to provide automatic control of swing phase of gait. As gait pattern and ambulatory endurance improved, wheelchair use was discontinued where possible so that walking became a primary method of mobility. To optimise outcomes in strength, endurance and standing balance a regimen of weight resistance training with pulleys and free weights, treadmill training and mat exercises were continued throughout the entire treatment period.

### 3. RESULTS

Mean MAL pre treatment ASIA motor score was 6.25. Mean post treatment MAL score was 17.5. 6 subjects improved their MAL motor score by > 200% (range 129% -433%). 2 subjects demonstrated initial MAL scores of 1 and 3, respectively with final scores of 17 and 16 respectively. Initial LAL scores for these subjects were similarly low at 2 and 8 respectively. Final LAL scores were 18 and 19 respectively. Combined improvement in MAL+LAL motor performance was therefore 32 and 24 points respectively. All subjects achieved independent ambulation at discharge. 7 subjects became fully ambulatory in the community (did not require a wheelchair). 3 Subjects were limited community walkers while 2 subjects managed household ambulation only. Mean MAL pre/post treatment motor scores for the 12 subjects based on final ambulatory outcomes are presented in Fig 1. Least affected limb pre/post scores in Fig 2. 4 subjects with unilateral weakness and an initial grade 0 of MAL dorsiflexion (DF) regained grade 4 DF on final testing. 1 subject with initial grade 2 MAL/DF regained a grade 4 final score. All other subjects regained grade 3 MAL/DF (vs initial grade 0 DF). Of note, all subjects regained a minimum of grade 3 hip flexion that when combined with active dorsiflexion provided sufficient foot clearance and limb advancement during the swing phase of gait. Ankle plantar flexors graded on final evaluation demonstrated a mean score of 3 (6 subjects) and



grade 4 in the remaining 6 subjects. In 5 subjects an ankle foot orthosis (AFO) was fitted to the most affected limb to provide mediolateral stability at the ankle, reduced hyperextension moment at the knee and improved heel strike during walking. [FES can also be combined with an AFO to improve walking speed as reported in a previous study<sup>5</sup>.]

#### 4. DISCUSSION AND CONCLUSIONS

In recent years, the trend towards early surgical stabilization of SCI patients has meant that early mobilization and active rehabilitation can be commenced within the first few weeks of injury. In the case of the incomplete SCI patient, early muscle activation with FES may hasten motor recovery. Muscle strengthening and gait re-training using FES may also lessen the deleterious effects of prolonged immobility and disuse atrophy that frequently were the sequelae of a spinal cord injury. This small sample study of FES in incomplete spinal cord injury has attempted to highlight a methodological approach to the application of FES as a means of improving lower extremity motor scores in the period immediately following the ISCI. Electrical activation of muscles below the level of injury may mitigate to some degree the disuse atrophy that would otherwise occur due to loss of normal

activation. The effect of afferent stimulation provided by FES may also play a role in the improved outcomes seen in this patient group who received early FES. Granat et al<sup>6</sup>, concluded, in a study of FES in ISCI subjects, that an increase in the strength of the hip flexors not directly exercised during FES gait training could be attributed to the effect of stimulation of the flexor withdrawal reflex. They suggest also that eliciting a motor response via an afferent pathway could be a means of strengthening certain muscle groups weakened due to SCI.

Predicting neurologic recovery and ambulatory potential is difficult in the incomplete SCI patient especially if there is a pattern of bilateral weakness. However, early FES application may lead to functional recovery of motoneurons and improvement of motor scores earlier in the rehabilitation phase. The objective should be to progress ASIA C patients to ASIA D. In Brown-Sequard syndromes where there is mostly unilateral weakness, every attempt should be made to strengthen the most affected limb so that the ASIA motor score discrepancy between most and least affected limb is reduced. Data from this pilot retrospective study would suggest that the use of FES as an early intervention strategy can assist this objective.

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