# COMPARISON OF FES TREATMENT IN THE STROKE AND SPINAL CORD INJURY PATIENT

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The techniques of Functional electrical stimulation (FES) have developed through the study of both stroke and sinal cord injury subjects. The earliest mention is by Kantorowitz [1] who reported using FES to help a paraplegic patient to stand. Liberson [2] was the first to report using an electrical stimulation device for foot-drop treatment in a stroke subject. Later, groups in Italy, the United States and Yugoslavia continued work on FES rehabilitation methods [3,4,5,6] and an implantable clinical device for FES correction of foot-drop was developed [7]. This basic device has been expanded to a 49 channel system [8] for paraplegic walking.

While there are many similarities in the FES treatment of the stroke and sinal cord-injury (SCI) subject, there are also many differences. There has been little prior discussion of these differences. Our center has worked with both groups os subjects over the past twenty years and Table I is a summary of our experience.

Major differences in the stroke and SCI patients may be generally classified as differences in mental, physical, and electrophysiological responses. While the SCI individual usually has some psychological problems with depression there is usually no cognitive deficit. The stroke individual, however, often has problems in cognition relating to memory, learning and reasoning ability. These cognitive deficiencies require a simple FES device interface and donning/doffing procedure. Functional use of the system must not require complex learning or conscious attention during ambulation. The device must operate automatically during the functional movement. In fact, a specific indication for lower extremity FES for the stroke patient is the inability to selectively control movement as a second order task; for example, an indication for FES benefit may be the inability to use a safe, energy efficient gait pattern while walking to someone or when distracted by an unexpected noise. Conversely, the SCI individual is capable of complex interaction with his device in achieving optimal function. Figure 1 illustrates the current CVAMC/CWRU stroke command interface while Figure 2 shows the paraplegic command interface.

There are also some major differences in physical condition between the two groups of patients. Stroke patients are older, often presenting with other diseases including cardiac and pulmonary diagnosis. While cardiovascular conditioning is certainly possible with both groups, great care must be taken first in properly setting the target heart rate and safe exercise intensity range for the post-stroke individual.

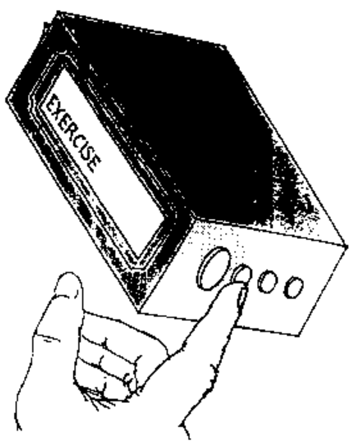


Figure 1. The control interface for a stroke subject consists of a series of push button switches on the stimulator-controller unit which is worn on a belt

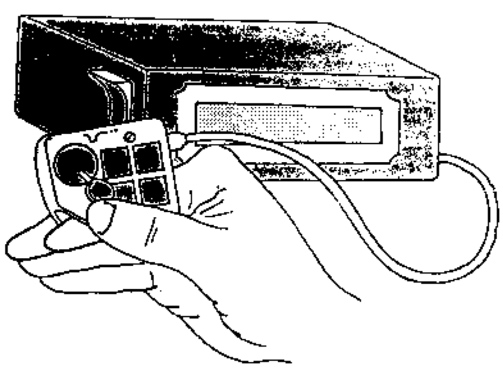

Figure 2.Control interface for paraplegic subject. The joystick command device is built into a large plastic ring which is worn on the index finger.

It is important that professionals involved with stroke and SCI patients appreciate the differences in electrophysiological response in the two conditions. Let us consider the moderately involved stroke subject and a similar partial SCI individual. FES control of eight channel of electrical stimulation is often sufficient to improve gait significantly in the paretic stroke individual.

Stimulation of eight muscles in the partial SCI subject can develop strong fatigue resistant muscles [9]. However, as these muscles become functional it becomes apparent that the unstimulated muscles that were just barely adequate for walking previously are no longer able to be controlled to function effectively in concept with the electrically-augmented muscles. Safe ambulation is not possible with eight FES driven muscles. The answer is to augment additional muscles. In our experience, we found that 48 channels were required for a full paraplegic (complete SCI) walking system to achieve a reasonable walking pattern: and 16 or more channels may be required for the partial SCI individual. Additionally, weakness and lack of proprioception can result in the easy development of painful "overuse" or "improper use" syndromes in the partial SCI individual. This phenomenon requires careful balancing of a more complex stimulation pattern that would initially appear necessary to compensate simply for muscle weakness.

JB is an example of the partial SCI subject ($T_4/T_5$) for whom repeated evaluation was necessary in order to detect changing motor system imbalance during treatment and to effectively treat the imbalance using the FES system. JB was initially ambulatory with Canadian crutches and KAFO. Electrodes were implanted in the more impaired right lower extremity. These included vastus lateralis, intermedius and medialis for knee control, posterior portion of adductor magnus, hamstring, and gluteus maximus for hip extension; and gluteus medius for mediolateral control of the hip. Iliopsoas and sartorius electrodes provided hip flexion during swing; and dorsiflexion control was

TABLE 1--LOWER EXTREMITY FNS PATIENTS

**Subject Group 1--Neuro Muscular Assist (NMA) Patients**

| | PRIOR TO STROKE | | DATA AT IMPLANTATION | | | | | FUNCTION ACHIEVED |
|---|---|---|---|---|---|---|---|---|
| CASE | SEX | HANDEDNESS | PRE-STUDY BRACE USED | AGE | MONTHS POST STROKE | PROBLEMS | YEARS POST OP | POST-STUDY BRACE USED |
| 1* | M | L | Double Upright | 52 | 60 | COMMUNICATION | 7.3 | 0 |
| 2 | M | R | External Electronic | 68 | 58 | EXT EQUIP+ | 7.1 | 0 |
| 3 | M | R | Double Upright | 46 | 24 | EXT EQUIP+ | 5.3 | 0 |
| 4 | F | R | Double Upright | 47 | 18 | NONE | 5.8 | 0 |
| 5** | M | R | Double Upright | 52 | 27 | EXT EQUIP+ | 5.8 | NMA |
| 6 | M | R | Double Upright | 60 | 71 | MI | 4.3 | 0 |
| 7 | F | R | Double Upright | 42 | 54 | VALGUS | | 0 |

*Implanted leg amputated 6/6/77, four years post implant. Patient died 6/8/80
**Patient died 3/31/79,
+External Equipment Failure

**Subject Group 2--Complete Spinal Cord Injured**

| CASE | ENTRY AGE | INJURY LEVEL | ENTRY FUNCTIONAL LEVEL | TIME IN STUDY (mos) | SPEED (RL) (m/sec) | DISTANCE (RL) (m) | STAIRS (mos) | POST FUNCTION ACHIEVED |
|---|---|---|---|---|---|---|---|---|
| 1 | 23 | T8 | WHEEL- | 76 | 0.6 | 330 | 20 | STAIRS |
| 2 | 23 | T5 | CHAIR | 43 | 0.2 | 55 | | WALKING |
| 3 | 21 | T4 | " | 44 | 0.7 | 250 | 23 | STAIRS |
| 4 | 27 | T11 | " | 51 | 0.7 | 90 | 13 | STAIRS |
| 5 | 38 | T9 | " | 78 | 0.5 | 800 | 6 | STAIRS |
| 6 | 23 | T7 | " | 72 | 0.3 | 100 | | WALKING |
| 7 | 28 | T8-T10 | " | 3 | | | | STANDING |
| 8 | 26 | T6 | " | 20 | | | | WALKING (parallel bars) |
| 9 | 29 | T7-T8 | " | 16 | | | | STANDING |
| 10 | 32 | T8 | " | 27 | 0.6 | 700 | 11 | STAIRS |
| 11 | 28 | T7 | " | 12 | | | | STANDING |
| 12 | 18 | T5-T6 | " | 44 | 0.3 | 45 | | WALKING |
| 13 | 40 | T5-T6 | " | 14 | | | | STANDING |

(RL) - walking with a rolling walker

TABLE 1 (continued) - LOWER EXTREMITY FNS PATIENTS

**Subject Group 3 - Partial Spinal Cord Injury and Stroke Patients**

| CASE | AGE | LEVEL OF INJURY ENTERING STUDY | ENTRY FUNCTIONAL LEVEL | TIME IN STUDY | IMPLANTATION DEVICE | FUNCTION ACHIEVED |
|---|---|---|---|---|---|---|
| 1 | 36 | C-5 due to Transverse Myelitis | Could get up by himself, walked using walker with excessive scissoring | 72 | 1 electrode per quadriceps, several others in abductors, hip flexors and extensors | Walked with marked reduction of scissoring, but lacked endurance |
| 2 | 57 | Stroke, Cerebro-vascular | Could stand up, but walked only backwards | 36 | 2 electrodes in iliopsoas, 2 in rectus femoris | Could walk 30 minutes or more unassisted |
| 3 | 25 | T4-T5 | Walked slowly with forearm crutches & long leg braces | 12 | Electrodes in right side gluteus maximus, quads, iliopsoas, plantar flexors, dorsiflexors, hamstrings | Walked faster, with a problem of instability on the "good" side |
| 4 | 66 | Hemiplegic left handed | Walked a few steps with a quad cane | 12 | Electrodes in gluteus, maximus quadriceps, iliopsoas, plantar flexors | Improved symmetry & endurance, problem with pain |
| 5 | 63 | Hemiplegic left handed | Could stand up with walker | 9 | 1 electrode in dorsiflexor, 1 in plantar flexor, 2 in adductors, abductors, trunk extensor, 5 in knee flexors, knee extensor, hip extensor, 3 in hip flexors | Walked an average of 402 feet with FNS in lab, given rests |
| 6 | 44 | Hemiplegic right handed | Community Walker | 24 | 2 electrodes in dorsiflexors, 2 in plantar flexors, 2 in knee extensors, 2 in knee flexors, 5 in hip flexors | Improved gait pattern for slow speed walking |

provided by implantation of the tibialis anterior. Gastrocnemius was implanted to provide push-off during ate stance. An FES rehabilitation program was initiated while various electrodes were added. After several months, it became apparent that the gait deficits were now during left swing and stance; ion addition, torso control problems became apparent. At least 12 electrodes would have been required for safe, functional walking. Since a totally implantable stimulator was not yet available, this subject withdrew from the program.

Another interesting difference in the two groups is the phenomenon of motor control improvement demonstrated by some stroke patients and not usually demonstrated by the SCI patient. First, a short term "carry over effect" is sometimes demonstrated by the stroke patient. After use of the FES system for a few weeks, it is possible to observe improved function for a day or more without further use of the FES device. One subject wears the FES device in the morning and states that this is enough to provide selective active foot dorsiflexion for the rest of the day [10,11,12]. This augmentation is entirely lost, however, after a day or so without stimulation. Another interesting phenomenon is motor retraining. Apparently the repetition of the proper pattern can result in permanent change. The stroke subject can sometimes develop selective active dorsiflexion which remains useful permanently even after years without further stimulation [13].

Our goal is to provide practical ambulation; practical ambulation is defined as that which the individual would chose to use on a daily basis. Our own experience coupled with that many others [14] indicates that the criteria for practical ambulation include: a walking rate of 1.0 meters par second; energy use for walking at the rate less than 50% of the individual 's maximum aerobic capacity; a donning and doffing time of only a few minutes; a failure rate of components of only a few times a year; and safety from both minor and major injury.

We have summarized differences in mental, physical and electrophysiological response between stroke and SCI subjects who receive FES treatment toward the goal of practical ambulation. As researchers and clinicians we must be alert to these differences and selectively apply sound rehabilitation principles which work well for each group. As the field of FES develops, the combined experience of many professionals will help to establish guidelines for FES application to a wide range of subject groups.

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