FUNCTIONAL ELECTRICAL STIMULATION USING EXTERNAL ELECTRODES: SOME PROBLEMS AND SOLUTIONS

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Abstract

An FES system using external electrodes was applied to individuals with spinal cord injury to allow standing and limited ambulation. The quadricep muscles were stimulated to provide knee stability and the peroneal nerve stimulated to provide a flexor withdrawal reflect for stepping. In conducting the program, four problems were identified and solutions found. (1) A continuous passive (CPM) motion machine was modified to provide electrical stimulation through the range of motion for strengthening. (2) An electrode garment was found to be a good method to apply electrodes but the electrode impedance of the commercially available garment tested was to high to work properly. (3) The use of stimulation over the glutus maximus and glutus medius reduces leg adductor spasticity problems which causes scissoring of the legs during walking. (4) One subject had a significant reduction in strength due either to overtraining (stimulated 4 to 6 hours/day) or to drinking a large amount of alcohol.

Key Words: muscle strength, electrodes, strength training, gait.

Introduction

Functional electrical stimulation (FES) using external electrodes was tested on a group of spinal cord injured individuals in order to evaluate the efficacy of the system to provide a method for exercise, therapeutic loading of the bones to prevent osteoporosis, and a practical standing system with limited ambulation capabilities. The view was that the system could be used in the home in a functional manner or for therapeutic conditioning. The focus of this report is to describe four problems that occurred when carrying out the program and the solutions obtained.

Methodology

The FES technology used was similar to that described by the group in Yugoslavia (1,2,3). A four-channel or six-channel stimulator was used which was designed in our laboratory. The stimulator output pulse duration was 250 microseconds at a rate of 40 pulses/second with a constant current output of up to 100 mA. The pulse was monophasic but transformer coupled to eliminate any net charge transfer. Two channels were used to stimulate the quadriceps for standing. To walk, a flexor withdraw reflex was activated by stimulating the peroneal nerve at the same time cutting out the quadricep stimulation.

Six subjects with incomplete spinal cord injuries were accepted into the program.

Table 1

Characteristics of Patients Involved with Gait Training

Patient Number	2	3	6
Sex	F	M	M
Age	28	25	28
Height[1]	155	173	173
Weight	145	140	145
Level of Injury	T3-T4	C7	T3-T5
Time since Injury[2]	3.5	.5	10[3]
			2.5[4]

1 in centimeters
2 in years
3 initial injury
4 shunt place to drain syrinx

Table 1 lists the characteristics of three of the subjects that participated in the gait training phase of the program. The general procedure was to first evaluate knee strength. If it was less than 55 Nm of torque, the subjects were placed on a home strengthening program. The home program used a small portable stimulator with repeatable stimulation cycle times of typically 6 seconds on and 12 seconds off. They were instructed to stimulate themselves one to two hours per day. Every two weeks they returned to the laboratory for knee extension strength evaluation. When their strength reached 55 Nm they were placed in a gait training program three days per week.

Results

In carrying out the program four problems were encountered. The following is a description of the problems and their solutions.

1. The first problem was the lack of obtaining adequate strengthening with electrical stimulation training program. The original approach to strengthening was to have the individual perform one or two hours of electrical stimulation allowing the leg to straighten from a bent position with repeated cycles of 15

to 20 seconds. The patient typically performed this activity in a bed with the leg bent by placing it on a pillow. With the leg straight, the quadriceps muscles are in a shortened position, which minimizes amount of force they can develop. This fact, along with the fact that the strengthening is occurring at only the straight leg position, reduces the amount of strengthening that occurs (4).

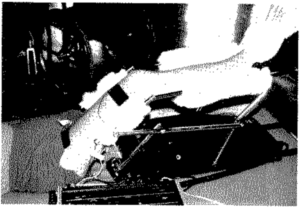

Figure 1. Continuous passive motion (CPM) device modified to provide electrical stimulation continuously during either flexion or extension for strength training.

Figure 1 shows a continuous **passive range of motion (CPM)** device (EMPI Corporation, Minneapolis, Minnesota, USA) that has been modified to provide continuous electrical stimulation to the quadriceps and glutus maximus muscles during extension and stimulation to the hamstrings during flexion. This device is powered by a motor that moves the leg at a constant rate. It can be attached rigidly to a bed. The device offers the possibility of providing continuous strengthening throughout the full range of motion in a relatively small device that can be used in **a** patient's home.

2. The second problem concerns **the development of external** electrodes **that could be rapidly applied and would remain securely in place. The first apparent solution to this problem was the use of an electrode garment as suggested by Petrofsky et al.(5) and manufactured by Bio-Stimu Trend Corporation (OpaLocka, Florida, USA). The garment has pockets for electrode paste (Figure 2) which are very convenient.**

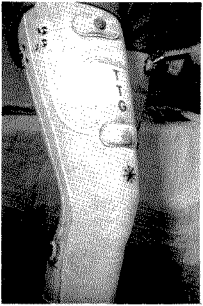

Figure 2. Electrode garment

The garment can be put on and removed very quickly and easily. When it is removed, it can be rolled up and placed in a sealed jar which prevents the paste from drying out. The electrode garment can then be reused the next day with very little effort The problem with the garment was the measured 6K ohms impedance of the electrodes. With this high impedance, it would take a 600 volts pulse to produce a current of 100 ma which is common for external stimulation of the quadriceps. The reason for the high impedance is the use of a single straight electrode wire in the paste pocket (Figure 3). A new garment is being designed that will incorporate a stainless steel wire mesh which will increase the electrode area to reduce the electrode impedance

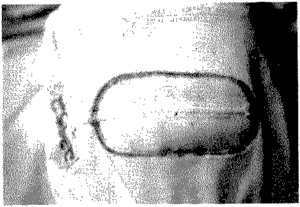

Figure 3. Electrode paste pocket in electrode **garment showing wire** used as electrode.

3. The third problem was the scissoring of **the legs that** occurred due to the adductor spasticity that was common **with most of the subjects.** Figure 4 shows an example of **the problem which with some subjects caused the legs to cross. The solution that seemed to help significantly was the addition of two additional channels of stimulation that was applied over the gluteus maximus muscle which probably also had overflow into the gluteus medius or the tensor fasciae latae muscle. This tended to cause abduction of the legs. The** timing **of the** channels **for the** gluteus maximus muscle was in parallel to the stimulation of **the** quadriceps.

Figure 4. Example of leg scissoring problem casued by adductor spasticity.

4. The fourth problem was the rapid fall in stimulation strength which occurred in one subject due possibly by overtraining. The patient was very enthusiastic when entering the program and wanted to obtain as much stimulation exercise as possible.

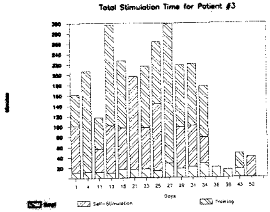

Figure 5. Total stimulation time as a function of time in program for subject 6.

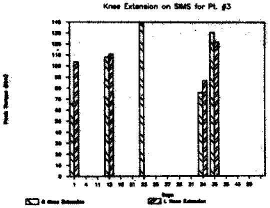

Figure 6. Knee torque for same subject shown in Figure 5.