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Restoration of Walking in Patients with Incomplete Spinal Cord Injuries by Use of Surface Electrical Stimulation—Preliminary Results†

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INTRODUCTION

A group of patients who are good candidates for the application of Functional Electrical Stimulation (FES) to restore reciprocal walking is described. They have incomplete lesions of the spinal cord. Because of the degree of preserved voluntary control, proprioception and sensation, some of these patients can achieve crutch assisted walking by means of multichannel electrical stimulation. In a number of cases the patient has sufficient strength and voluntary control in the upper limbs and at least one leg to provide safe standing for short periods in forearm crutches. For these patients a two channel stimulator controlled by a handswitch was applied to achive safe and practical crutch assisted walking in a relatively short period of time.

BACKGROUND

A new group of patient which can benefit from the orthotic use of functional electrical stimulation (FES) has been identified. These are incomplete spinal cord injured patients. This group of patients is increasing in numbers mainly due to improvements in primary care.

The clinically incomplete lesion of their spinal cord results in preservation of some voluntary movements of the lower extremities. Some of these patients are able to walk with the help of various short-leg or long-leg orthoses which fix the knee and ankle joints. Support of the foot is often provided by the addition of a toe spring. Locomotion of most other incomplete spinal cord injured (SCI) patients is performed with the help of a wheelchair. They can walk only for very short distances, usually in their homes. Some tetraplegic patients are totally confined to a wheelchair. The reason is often very strong spasticity or developed contractures. The upper extremities are also partially paralyzed. Nevertheless, the arms and hands are strong enough to provide support on crutches. Wrist and finger movements are often limited and the grip is rather weak. However, the patients are in most cases able to hold the handle of the crutch.

It was found that a minimum of four channels of FES was required for synthesis of a simple reciprocal gait pattern in the complete

thoracic patient (Bajd et al., 1983; Kralj et al., 1983). During the stance phase, knee extensor muscles are stimulated, while the swing phase is accomplished by eliciting a synergistic flexor response in hip, knee and ankle joints through electrical stimulation of an afferent nerve. It was observed in the present study that in most of the incomplete tetraplegic patients one leg was almost completely paralyzed while the other leg was under voluntary control and sufficiently strong to provide safe standing for short periods using only crutches. Unilateral stimulation of knee extensors and an afferent nerve was helpful in these patients. Less frequently it was found that the patients could stand but were unable to take a step with one or both legs. Unilateral or bilateral stimulation of afferent nerves proved helpful for them. There are also patients whose extension and flexion capabilities in both lower extremities are so poor that they need three or even four channels of stimulation.

THE FES ORTHOSIS

From the point of view of control of the patient, the gait cycle was divided into stance and swing phase. The transition from one phase to another was achieved by pressing a hand switch mounted on the handle of the crutch. When the switch was not pressed, knee extensors were stimulated. When the switch was pressed, the afferent nerve was excited, resulting in the swing phase of walking. The duration of the swing phase was regulated by the time of pressing the switch. In the present investigation the peroneal nerve was stimulated near fossa poplitea. The stimulation of this mixed, sensory and motor, nerve provided direct dorsiflexion and eversion of the foot and simultaneously also the reflex knee and hip flexion.

The gait of most of the incomplete SCI patients can be restored by the two-channel stimulator only. Any stimulator can be used for the described application where the stimulation parameters can be adjusted close to the following values: 0.3 ms pulse duration, 20 Hz pulse repetition frequency, and an amplitude up to 120 volts (measured with a 1k Ω load). Surface electrical stimulation of the knee extensors was delivered to the muscles through large (6 × 4 cm) sheet metal electrodes covered with water soaked layers of gauze. When stimulating the common peroneal nerve, two small round electrodes (diameter 2.5 cm) made of sheet metal and covered by gauze saturated with water were used. The interconnection of the hand switch with the outputs of the stimulator to the electrodes can be readily accomplished. The hand switch was attached to the handle of the crutch by adhesive tape for trial purposes.

PATIENT TESTS

Five patients with incomplete spinal cord lesions have so far been included in the program of FES assisted walking. Only a short strengthening program was required for disuse atrophy of their thigh muscles. The learning program of walking was extremely fast and simple. After the first few days the patients were able to go

Figure 1. Paraplegic subject with incomplete lesions at T6/7 walking on a level surface.

Figure 2. Tetraplegic subject with incomplete lesion at C6 negotiating uneven steps.

Figure 3. Patient walking on uneven ground; end of swing phase for the paralyzed leg.

from mobile parallel bars to crutches (Figure 1). The difference between walking with and without FES was evident. The patients were not able to take a single step with their severely paralyzed extremity when the stimulator was switched off. After a few days of training they were able to rise from the sitting to the standing position independently with the help of the crutch support and knee extensor stimulation only. Soon they were able to walk on uneven ground (Figure 3) and go up and down steps (Figure 2). The subject shown in Figure 3 has an incomplete lesion at the level T6/7 (age 36 yrs., height 168 cm., mass 61 kg., 7 yrs. post injury). The subject shown in Figures 1 and 2 has an incomplete lesion at the level C6 (age 21 yrs., height 188 cm., mass 70 kg., 3 yrs. post injury). In both cases one leg was paralysed while the other had sufficient voluntary control to maintain safe standing with crutches without stimulation.

DISCUSSION

Such activities can only be achieved in a few completely paraplegic patients after many months in the training program. These differences between incomplete and complete spinal cord injured patients are due not only to the remaining voluntary movements of their lower extremities, but also to the preserved sensation and proprioception. The present FES orthotic systems provide active movements at the joints of the limbs, but no feedback is available in practical clinical systems. The patients feel safe and secure when unattended because in the event of a failure of the orthosis, they are able to support themselves. For these reasons the incomplete SCI patients appear to be the most appropriate candidates for FES. The FES assisted walking may require less energy from the SCI patients with incomplete lesions than walking with passive mechanical knee and

ankle orthoses, because no hip hiking is necessary with active FES systems. Finally, FES assisted walking is much more aesthetic to the observer than orthoses assisted and is preferred by the patients. There may be a number of therapeutic benefits to be gained from the use of FES orthoses such as the prevention of pressure sores, contractures, muscle atrophy and bone demineralisation.

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