Clinical Application of the Hybrid FES in a T4 Completely Paraplegic Patient

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Abstract – *T4 complete paraplegia shows trunk instability, therefore it is difficult to stand and walk. We restored the ambulation in a 21-year-old man with T4 level complete paraplegia using a hybrid FES. The hybrid FES system consisted of a 12-channel stimulater, percutaneous intramuscular electrodes and the Walkabout orthosis. Evaluation was based on 1) standing-up motion analysis, 2) the distance of the centers of pressure while standing, 3) gait analysis using the PEAK motion analysis system. In the results, the patient could stand up with hybrid FES. The gross area of center of pressure was 2.79 cm2 with FES, and 4.27 cm2 without FES (P< .05). The step length was 42cm with FES, and 28cm without FES. The hybrid FES system in conjunction with the paravertebral muscle provides optimum performance in T4 complete paraplegia.*

Keywords: paravertebral muscle, quadriceps muscle, T4 complete paraplegia, Hybrid FES

1. Introduction

Although paraplegic patients can ambulate using a wheelchair, standing and walking gives them functional, physiological, and psychological advantages [1]. Functional electrical stimulation (FES) has been applied to patients who have a spinal cord injury or have lost supraspinal control of α-motoneurons for other reasons [2]. We have used FES to restore paralyzed muscles since 1990. [3] Since a paraplegic patients ambulation has high energy cost, we have used several type of hybrid FES using FRO, AKJ, RGO and Walkabout to prevent muscle fatigue, reduce energy consumption, and enable better stability in the lower extremities [4]. However high thoracic paraplegia shows trunk instability, therefore it is difficult to stand and walk.

The purpose of this study was to investigate the effects of the Hybrid functional electrical stimulation (Hybrid FES) with stimulation of back muscle and hip joint muscles to maintain the trunk stability in a T4 complete paraplegic patient.

2. Subjects and Methods

A 21-year-old man with T4 level complete paraplegia, who was injured 1.5 years ago in a traffic accident, participated in this study. The patient was treated with the hybrid FES using 40 percutaneous intramuscular electrodes and the Walkabout orthosis. The percutaneous intramuscular electrodes were implanted into the motor points of the paravertebral muscle, psoas major, vastus lateralis, vastus medialis, sartorius, tensor fasciae latae, gluteus maximus, gluteus medius, biceps femoris, adductor magnus and implanted near the femoral nerve and peroneal nerve.

The FES system with the Akita stimulator III (BIOTEC, LTD, Japan) was used to restore the function of standing-up, standing and walking. The stimulator which had 12 channels (**Fig. 1**). The pulse amplitude was modulated from 0 to –15V. Rectangular pulse trains were used with 200 microseconds pulse width and a pulse interval of 50ms.

Evaluation was based on three methods. 1) Standing-up motion analysis from wheelchair with parallel bar using the PEAK motion analysis system (Motus, LTD, USA). The knee joint of the Walkabout orthosis were unlocked so as not to hinder natural standing, using a standing-up pattern of the FES by Kagaya and associates [5].

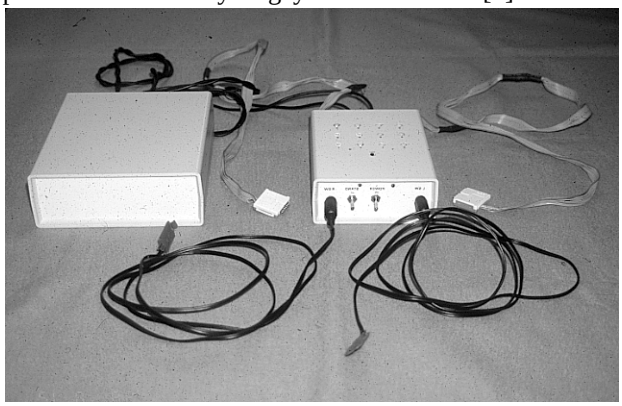

Fig 1. Akita stimulator III had 12 channels and two hand switches. Rectangular pulse trains consist of a pulse width of 200 microseconds, a pulse interval of 50ms, and pulse amplitude from 0 to –15V.

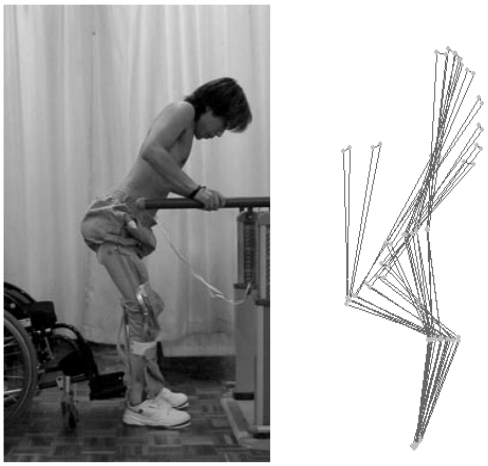

Fig 2. Standing-up motion from wheelchair with FES. The stick picture shows natural standing by the FES. The reflective markers were placed on the acromion of the shoulder,the greater trochanter of the femur and the lateral malleolus.

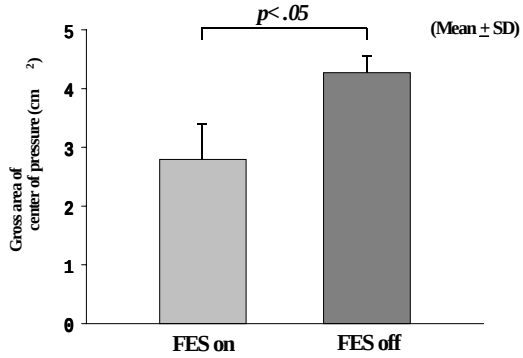

Fig 4. The gross area of center of pressure while standing motionless with and without FES on the force plate. The gross area of center of pressure with FES was less then without FES. There was a significant difference (p< .05) between with and without FES.

Reflective markers were placed on these sites: over the acromion of the both shoulder, over the greater trochanter of both femurs, over the lateral malleolus. The standing-up motion digitized at a rate of 60Hz using PEAK motion analysis system. 2) The distance of the centers of pressure while standing motionless with or without FES on the force plate (9281B, Kistler). According to Andrews and associates, [6] if a subject leans slightly forward with hips and knees fully extended during standing, the floor reaction force passes in front of the knee joint and the leg is mechanically stable. This posture is often referred to as the "C" posture. Our subjects were asked to adopt this posture while standing with or without the FES. While standing motionless on the force plate, the floor reaction force digitized at a rate of 30Hz for 30 seconds. 3) Gait analysis using the PEAK motion analysis system. A subject walked 5m using the aid of a parallel bar. Reflective markers were placed on these sites: over the lateral malleolus, over the greater trochanter of the femur, and over the acromion of the shoulder. The gait was digitized at a rate of 60Hz using the PEAK motion analysis system. A range of motion of the trunk and the step lengths were determined.

3. Results

Standing-up transition

The patient could stand-up with hybrid FES (**fig. 2**). It is shown in the stick picture that standing-up was very natural. The muscle force and muscle fatigue of the upper extremities with FES was less than without FES.

The gross area of center of pressure

It was difficult to stand motionless without FES. The upper extremities were elevated to keep a balance. However it was possible to stand with FES (**fig. 3**). The means for the gross area of center of pressure with and without FES were 2.79 cm2 and 4.27 cm2 (**fig. 4**). There

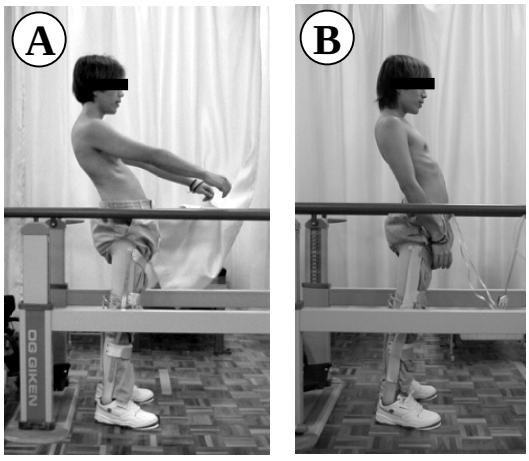

Fig 3. Standing with and without FES. (A) FES off. It was difficult to stand, the upper extremities were elevated to keep a balance. (B) FES on. He was possible to stand without upper extremities elevation.

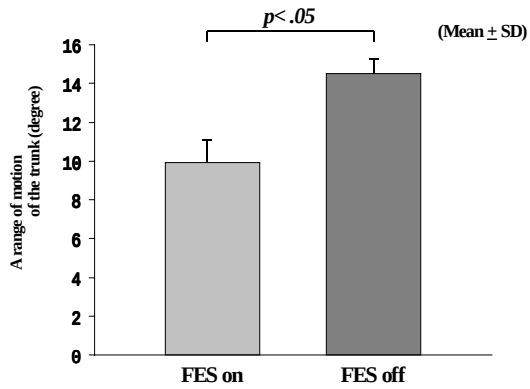

Fig 5. A range of motion (ROM) of the trunk in gait. A ROM of the trunk with FES was less than without FES. There was a significant difference (p< .05) between with and without FES.

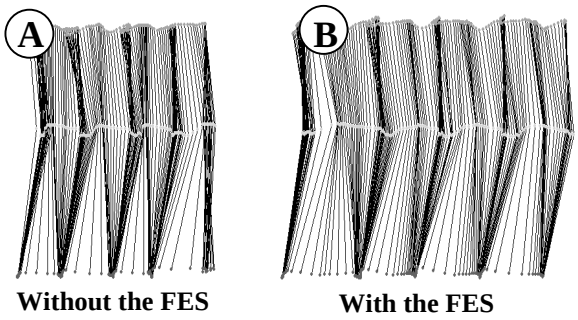

Fig 6. The stick picture during gait motion. (A) without FES. (B) with FES. The step length with FES was greater than without FES.

was a significant difference ($p < .05$) between both methods, respectively.

Gait analysis in the FES

A range of motion of the trunk with and without FES were 9.9 degrees and 14.5 degrees. There was a significant difference ($p < .05$) between both methods (**fig. 5**). The trunk instability with FES was less than without FES. The best data of the step length was 42cm with FES, and 28cm without FES (**fig. 6**).

4. Discussions

In restoring locomotion in complete paraplegic patients, it is necessary to control the lower extremities joints and to control the trunk muscles in order to maintain an upright posture during standing and walking. According to Andrews, [6] the "C" posture is mechanically stable. Our complete paraplegic patients were asked to adopt this posture. However it is important that T4 complete paraplegia shows trunk instability at the front and back. In this study, we attempted to stimulate the paravertebral muscle and quadriceps muscles simultaneously to maintain balance. The FES with paravertebral muscle and quadriceps muscles stimulation provides stability in the trunk and allows the subjects to walk using longer step length. Using FES allowed them to move their legs more easily and to transfer weight with less effort. [7] The hybrid FES system in conjunction with the paravertebral muscle and quadriceps muscles provides optimum performance in T4 complete paraplegia.

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