Functional electrical stimulation in Akita FES Project

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1. INTRODUCTION

The Akita FES Project has introduced functional electrical stimulation (FES) for restoration of paralyzed upper and lower extremities in spinal cord injuries and hemiplegic patients since 1993. Percutaneous intramuscular electrodes and a portable multichannel system were used for many patients. Recently, we have introduced functional magnetic stimulation (FMS) using R-F microstimulator with a minimally invasive implantation and retrieval technique. Here, we describe the clinical and experimental applications of FES in Akita FES Project, Japan.

2. Hybrid Functional Electrical Stimulation with Medial Linkage Knee-Ankle-Foot Orthoses in Complete Paraplegics

We have previously restored ambulation in paraplegics by performing hybrid functional electrical stimulation (FES) using medial linkage knee-ankle-foot orthosis (MLKAFO). The most common MLKAFO (hinge-type MLKAFO) has the hypothetical axis that is lower than the physiological hip joint position, resulting in slow velocity and short step length. A new MLKAFO (sliding-type MLKAFO), which uses sliding medial linkages, has been developed to correct the axial discrepancy of the hinge-type MLKAFO that causes limited hip joint excursion. There have been reports of instability associated with sliding medial linkages, but the mechanism of this instability is unclear. The purpose of the present study was to evaluate the effects of FES with MLKAFOs on ambulation in paraplegics. Complete paraplegic patients participated in this study. Kinematics data during ambulation were obtained using a motion analysis system. We measured gait velocity and hip progression during the standing phase. The sliding-type MLKAFO produced faster gait velocity than did the hinge-type MLKAFO, but it caused pelvis instability without FES. Pelvis instability was controlled by hybrid FES using the sliding-type MLKAFO. With hybrid FES, the sliding-type MLKAFO provides better gait performance than the hinge-type MLKAFO, but the hinge-type MLKAFO provides greater pelvis stability during walking. Moreover, FES provided sufficient propulsion to allow the complete paraplegics to walk.

3. Clinical Application of Peroneal Nerve Stimulator System Using Percutaneous Intramuscular Electrodes for Correction of Foot Drop in Hemiplegic Patients

We assessed the orthotic effect of a functional electrical stimulation device (Akita Heel Sensor System; AHSS) in the treatment of hemiplegic foot drop gait. In the AHSS, a heel sensor is attached to a small plastic heel brace, and the peroneal nerve is stimulated via percutaneous intramuscular electrodes. During the swing phase of the hemiplegic gait, the common peroneal nerve is stimulated by the AHSS. Eight patients in chronic stages of hemiplegia participated in this study. Walking speeds and step cadences on a 10-m course were compared between walking with stimulation and walking without stimulation. Mean walking speed (± SD) was 0.50 ± .26 m/s without stimulation and 0.64 ± .31 m/s with stimulation. The mean percent increase in walking speed with stimulation was 30.1%. Mean step cadence was 31 ± 7 steps/10 m without stimulation and 27 ± 7 steps/10 m with stimulation. The AHSS significantly corrected foot drop (p < 0.05). We
concluded that the AHSS can significantly correct foot drop in hemiplegic patients.

4. Grasping Power by Means of Functional Electrical Stimulation in Complete Tetraplegia

Grasping power (GP) by means of functional electrical stimulation (FES) was measured in complete tetraplegia. These were compared with GP by means of the dynamic tenodesis effect, the flexor hinge splint and the GP of normal female. Palmar grasp strength by means of FES was approximately 16% of the control group and 2.4 times greater than the flexor hinge splint. Lateral grasp strength by FES was approximately 13% of the control group. Our results suggest that FES is more effective than the flexor hinge splint in increasing the GP of tetraplegic patients, and that a stronger and stable GP, which is not affected by wrist position, makes FES practical for improving activities of daily living (ADL).

5. The Akita Functional Electrical-Assisted Rowing Machine

Resistance training equipment is effective for prevention of muscle atrophy in not only healthy people but also the elderly, and even disabled individuals. The purpose of this study was to develop rehabilitation equipment for wheel-chair users or elderly people with limited mobility. Functional electrical stimulation (FES) has been used to restore a lost function in disabled patients. We devised the prototypical FES-rowing machine device, with easier transfer in mind, incorporating a controller of lower limbs and a trunk stabilizer. An able-bodied individual participated to test the new equipment. A measurement system included the experimental rowing machine with six force-sensing resistors and a three-dimensional motion analyzer. A two-channel electrical stimulator using surface electrodes activated the quadriceps femoris muscles in drive phases of the rowing cycle. A four-link model was used to calculate the joint moment. The knee extension moment from the end of the pull phase to the flexed ready position was approximately 2 times that at the stroke start. Comparing general rowing and FES-rowing, no significant difference was observed in joint moment and range of movement. Our results suggest that safe, effective training is possible for seniors and paraplegics if postural stability is maintained during FES-rowing.

6. Functional Magnetic Stimulation using the RF-Microstimulator to Relieve Pain due to Shoulder Subluxation in Chronic Hemiplegic Stroke

We evaluated the ability to relieve shoulder pain by implanting ceramic-case versions of RF-Microstimulators (RFM) in paralyzed shoulder muscles. A 66-year-old male patient, who had left-sided chronic hemiplegia due to a stroke five years previously, had developed shoulder subluxation resulting in pain. Two RFM devices were implanted, one next to the axillary nerve and one at the motor point of the middle deltoid muscle. Electrical stimulation at both sites was commenced two weeks after implantation for a 6-month period. Our evaluation of the effectiveness of the RFM devices has been by measuring pain (using the visual analog scale: VAS), range of motion at the shoulder, strength of the deltoïd muscle, degree of shoulder subluxation, and muscle atrophy. Following commencement of stimulation, follow-up evaluations were performed at 1, 2, 3, 4, and 6 weeks, 3 and 6 months, and after 6 months of no stimulation. During the treatment period of 6 months of stimulation, the patient’s pain had reduced from 70 to 0 on the visual analog scale. At 6 months after completion of the treatment, relief of pain and effective evoked muscle contraction have remained. Although these results suggest that the feasibility of using RFM devices implanted both epineurally to the axillary nerve and next to the muscle motor point in this one patient, to relieve pain and elicit contraction, further investigation is needed to demonstrate the clinical feasibility of using RFMs for treating post-stroke shoulder pain.

7. Effects of therapeutic magnetic stimulation on acute muscle atrophy in rats after hindlimb suspension

In most subjects with spinal cord injury, the spinal neurons below the level of injury are spared. Therefore, it is conceivable that the skeletal muscles innervated by these spinal nerves can be activated by applying therapeutic magnetic stimulation along the dorsal spine. The purpose of this study was to evaluate the ability of magnetic stimulation to prevent acute muscle atrophy in rats after hindlimb suspension. Forty adult male Wister rats were randomly assigned to stimulated and non-
stimulated (control) groups. Their hindlimbs were unweighted using a suspension method, causing muscle atrophy. In the stimulation group, magnetic stimulation (20 Hz, 60 minutes per day) was applied to the sciatic nerve for 10 days. After the stimulation period, the tibialis anterior (TA) and extensor digitorum longus (EDL) were surgically removed and histologically measured. The lesser fiber diameters of type 1, 2A, and 2B muscle fibers were significantly greater in the stimulated group than in the non-stimulated group for both the TA and EDL (p < 0.05). The mean difference in lesser fiber diameter was 20% (range, 14% - 27%). These results suggest that therapeutic magnetic stimulation is an effective method of preventing muscle atrophy.

8. Biomechanical Measurement of Swing-Through Gait using a Mathematical Link Model

Techniques are required to determine the muscle forces, joint forces, and joint moments of the shoulder, back, and elbow when performing the swing-through gait. Furthermore, the effects of the reaction forces of the feet and crutches on the arms when performing the swing-through gait have not been determined. Muscular moments of the arms are important parameters when computing joint forces. However, measurements in vivo have not considered the possibility of a change in joint position due to muscle activity and measurements have only been obtained from a two dimensional platform. Three-dimensional (3D) measurements obtained from the motion analysis system and force plates have been used to develop programs for Matlab 6.5 (Math Works Co., USA) to solve for joint moments, muscle forces, joint forces, and the reaction forces of the arms, crutches, and feet when performing the swing-through gait. Data from swing-through gait analysis of the shoulder, back and elbow shows a significant increase in the joint and muscle forces, as joint moments move in the positive and negative directions when crutches contact the floor. Data obtained from this analysis of the arm showed a large increase in the joint moment, joint force, and muscle force of the arms when the crutches contact the ground. The increase in the joint and muscle forces is due to shifting of the body mass from the feet to the crutches, which was also evident from force plate data. The joint moment increased because of the significant arm movement in the negative direction. Such 3D analysis of the arm provides more accurate information about the effects of the muscles and the reaction forces of the feet and crutches on the shoulder and elbow when performing the swing-through gait.

References