*Proceedings of the Eighth International Symposium on ECHE, 1984, Dubrovnik*

# LIMB FLEXION DEFICITS: IMPLICATIONS FOR FES GAIT ASSIST DESIGN

Perry, J., M.D.; Barto, P., R.P.T., B.S.
Gronley, J., R.P.T., M.A. and Yoshida, H., M.S.

Pathokinesiology Service, Rancho Los Amigos Medical Center

In the United States there is an existing population of 150 to 500,000 persons with spinal cord injuries. Seven to ten thousand new injuries occur each year. Improved care of acute spinal cord injuries has led to half of the patients having incomplete lesions. However, ambulation is achieved in only 30% of this group or 25% of the total SCI population, leaving a large number of patients in need of gait assistance.

On the assumption that individuals with some residual motor power will attain greater functional improvement in ambulation from F.E.S. than those with no motor control, we have begun to investigate patterns of muscle action in incomplete lesions. One purpose of this study was to determine which clinical tests best identify residual function. The other objective was to delineate the patterns of muscle action that occur in gait.

## METHOD

From the Rancho outpatient S.C.I. clinic, four teen patients with incomplete injuries were identified as having inadequate limb flexion as a primary gait defecit. Laboratory testing assessed muscle strength, upright motor control and the patients´ gait.

Muscle activity was evaluated by intramuscular dynamic electromyography. 50 micron wire electrodes were inserted into the tested muscles by 25 gauge needles. The free ends of the wire were connected to ground plates taped to the subject´s leg. Following cable transmission to a bio-sentry EMG transmitter, the myoelectric signal was differentially amplified and then telemetered to the recording/display complex. EMG signals were printed out on light sensitive visigraph paper for immediate visual analysis as well as stored on 7-channel analog tape for computer quantification.

Among the muscles studied, three were hip flexors: iliacus, rectus and sartorius. Hip extensor activity was represented by semimembranosis. The biceps femoris short head and sartorius served as knee flexors. Knee extension was represented by vastus lateralis and rectus. The soleus was monitored as an ankle plantar flexor capable of restricting pre-swing knee flexion.

Muscle strength was assessed during both selective and patterned movements. The muscle´s performance was graded using conventional manual muscle testing criterion. These grades were converted to the percent of normal torque equivalents developed by Beasley.

Upright motor control testing evaluated erect pattern strength. In addition to myoelectric activity, limb motion was evaluated in this test with the aid of a two-dimensional motion analysis system. Reflective markers placed on the sacrum, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, lateral femoral epicondyle, fibular shaft, heel and fifth metatarsal head defined pelvic, thigh, knee and ankle motion.

Muscle activity, limb motion and stride characteristics were assessed during gait. The functional gait effort produced by each muscle was calculated by the formula:

$$\frac{\text{Gait EMG}}{\text{Muscle Test EMG}} \times \text{Muscle Test Grade (Beasley equivalent)}$$

A survey of the patient´s functional use of ambulation in home and community activities was performed. The Hoffer classification scheme was used to rate subjects as physiological, household, limited community or unlimited community walkers.

RESULTS

The fourteen tested patients comprised three separate groups of walkers differing in velocity, upper extremity support and functional ambulation characteristics. Poor walkers were characterized by low walking speeds and high support requirements. Intermediate walkers ambulated either at low speeds with little weight born on assistive devices or achieved higher velocities as a consequence of high reliance on equipment. Good walkers displayed high velocities with minimal upper extremity support needs.

As velocity increased and support decreased, ambulation was used in more activities. Poor walkers ambulated for exercise only, in the home only, or in just a few community activities. The walkers in the intermediate group were classified as limited community walkers in the Hoffer classification scheme. While independent in the home, they frequently preferred the wheelchair for community activities. The good walkers displayed infrequent wheelchair use, routinely walking in the community.

Gait characteristics varied noticeably between poor and good walkers. Median velocity in the poor group was 18% N, with good walkers ambulating at 60% of normal walking speed. Cadence was decreased in the poor walkers to 39 steps/min in contrast with 92 steps/min taken by the good walkers. Stride length was 1/2 of normal or.8 m/stride in the poor group with good walkers reaching 1.2 m/stride. In the poor walkers, support requirements during stance were 36% of body weight and in swing were 29% of body weight. Good walkers demonstrated minimal support needs requiring only 3% of body weighting support during stance and 7% of body weight support in swing.

The percent of the gait cycle spent in double limb, single limb support and swing in the good walkers was similar to normal. The gait cycle of the poor walkers was characterized by long double limb support relating to difficulty in weight transfer and initiation of limb flexion.

The poor walkers difficulty in taking a step was characterized by both a delay in thigh advancement and an inadequate arc. By the time in the swing cycle when the normal thigh has achieved $20^{o}$ of flexion (.14 sec) the poor walker's thigh still trailed. Thus their initial swing was incomplete. By mid-swing when the normal thigh has achieved full flexion, the poor walkers had only advanced $9^{o}$ and their maximal thigh flexion of $17^{o}$ was delayed until 94 to 100% of the gait cycle.

Two-thirds of the poor walkers displayed some hip flexor activity in swing. Iliacus functioned in six persons, rectus activity was demonstrated in six and 5 had sartorius activity. Reduced intensity of hip flexor activity was a common and significant finding. Median iliacus gait effort in the poor walkers was only 5% N with rectus effort being 3% N and sartorius 4% N. In contrast, normal walkers display efforts of 20 to 30% of maximal muscle test EMG during swing.

The second most significant finding in the poor walkers was delay of onset of activity in swing. Only 6 of 27 hip flexor muscles demonstrated timely onset. Ten muscles were delayed from .04 to 1.5 seconds and 11 muscles were inactive.

The semimembranosis displayed inappropriate early swing activity in six of the poor walkers and was associated with decreased swing thigh flexion.

Knee motion was similarly imapired in the poor walkers. Pre-swing knee flexion was reduced to 12$^{o}$ while initial swing knee motion only reached 18$^{o}$ or 1/3 of normal requirements.

Six subjects displayed some knee flexor activity in swing with biceps femoris short head being active in five persons and sartorius in five. Decreased intensity of action again was demonstrated. Only two muscles had no delay in onset with 7 muscles being delayed .03 to 1.5 seconds. 9 muscles were inactive.

Antagonistic activity in pre-swing of soleus, vastus lateralis and rectus appeared to be a major factor restricting pre-swing knee flexion.

Among the three clinical tests, the upright motor control test produced similar amounts of EMG activity to that observed during walking. This flexion of 8 to 54$^{o}$ in the upright motor control test took 2.23 to 4.85 seconds to accomplish, a delay mirrored in gait. The patterned muscle test best elicited maximal muscle activity. In all but a few instances patterned muscle test EMG intensity exceeded gait EMG intensity, demonstrating an available reservoir of muscle power that could respond to FES gait assistance. The standard muscle test which relies on selective control was ineffective in predicting gait response.

DISCUSSION

Evaluation of 14 patients with incomplete SCI lesions has demonstrated the availability of a useful reservoir of muscle power for FES gait assist. Primary problems identified were insufficient intensity of hip flexors muscles contraction in swing and delayed onset of activity. These two deficits led to inadequate thigh flexion in swing with functional impairments of toe-clearance and momentum. Similar deficits in knee flexor activity also contributed to the impaired toe-clearance. Antagonistic extensor activity was a third major problem contributing to decreased flexion. Clinical management of this spasticity may be required prior to FES gait assist in this population.

For planning FES gait assistance, the value of clinical testing varied with the question to be answered. The U.M.C. test was most informative in predicting the amount of muscle action that the patient was likely to use in walking. If, however, one wished to know the available muscle power present, a gross patterned strength test was most appropriate. There appears to be no value in applying the standard selective manual muscle test to patients with upper motor neuron lesions.

A pilot study at Rancho of energy cost of walking in these patients has suggested a physiological basis for functional ambulation restrictions in the poor walkers. Routine community activities require negotiation of distances of at least 300 meters. At a walking speed of 16 m/min or 18% N, 20 minutes is required to traverse that distance.

In this energy cost study, 02 consumption expressed in ml./kg/min was found to be markedly higher in the household as opposed to the community ambulators. Further findings of elevated respiratory quotients in the household walkers suggest that anaerobic pathways must be utilized in order to sustain high energy requirements. Consequently, sustained ambulation is impaired.

It is hoped that FES gait assist will decrease the need for upper extremity support, lower energy costs and consequently improve functional ambulation skills in the S.C.I. population.