EXPERIENCES WITH FES ENABLED STANDING IN COMPLETE PARAPLEGIC PATIENTS

A.Kralj, T.Bajd, R.Turk*, M.Štefančič*, H.Benko*, and J.Šega

Faculty of Electrical Engineering, Edvard Kardelj University, Ljubljana, Yugoslavia

*Rehabilitation Institute, Ljubljana, Yugoslavia

Abstract

A method of paraplegic patients standing by means of surface two-channel electrical stimulation and wheel-chair attached collapsible supporting frame was developed. The advantages and disadvantages of the method are critically discussed and the problems encountered analyzed. The patients selection and rehabilitation process of functional electrical stimulation assisted standing are described together with the independent home use of the orthotic device. The stimulator together with the supporting frame enables to the patient to stand up to one hour at any location. Such a standing can be performed during several functional activities of daily life.

Introduction

Recently functional electrical stimulation (FES) has been introduced also into the rehabilitation program of spinal cord injured patients with upper motor neuron lesions. It is used to strengthen disuse atrophied muscles of complete and incomplete paraplegics and quadriplegics; it prevents further muscle atrophy; it provides better blood flow within the stimulated extremity; and it can prevent contractures (1). A two-channel electrical stimulator has been built which is intended to enable standing in complete paraplegic patients (2). More than one hour of secure standing can be achieved by locking knee joints through the electrical stimulation of both knee extensors. Standing of the paraplegic patient has been started to prevent pressure sores and to improve the functioning of internal organs.

If standing is to be a useful functional activity (e.g. to reach an object placed highly) a person must be able to rise from sitting to the standing position independently. It has already been shown (3) that standing-up of a complete paraplegic patient can be achieved by stimulation of the hip and knee extensors and ankle plantar flexors of both lower limbs. However, present six-channel stimulators are not convenient for every day patient's use. A standing procedure in which only the knee extensor muscle groups have to be stimulated was therefore developed (4). In this way the same two-channel stimulator can be applied for both prolonged standing and standing-up. The patient is assisting the FES by lifting the body with arms.

Functional electrical stimulation has the potential to become an effective orthotic tool in the rehabilitation process of complete and incomplete spinal cord injured patients. Compared to ordinarily used long leg mechanical braces (calipers),

it has several important advantages.Stimulating electrodes can be mounted on the extremity much easier and faster than mechanical orthoses. Stimulator is about the same price or even less expensive than calipers as it's production does not depend on the size of the patient's extremity. Probably the most important is the fact that FES uses the patient's own muscles which are with other rehabilitation methods completely useless. It can therefore be expected that the FES approach will improve the locomotion abilities of spinal cord injured patients in the near future. Standing and standing-up will represent an integral part of this rehabilitation method.

Stimulation properties

A two-channel stimulator intended for patient's independent home use was developed. Application of the stimulator consists of mounting a pair of surface electrodes over both knee extensor muscles. In Fig. 1 the two-channel stimulator is presented. Surface foam rubber-covered metal plate electrodes were used.

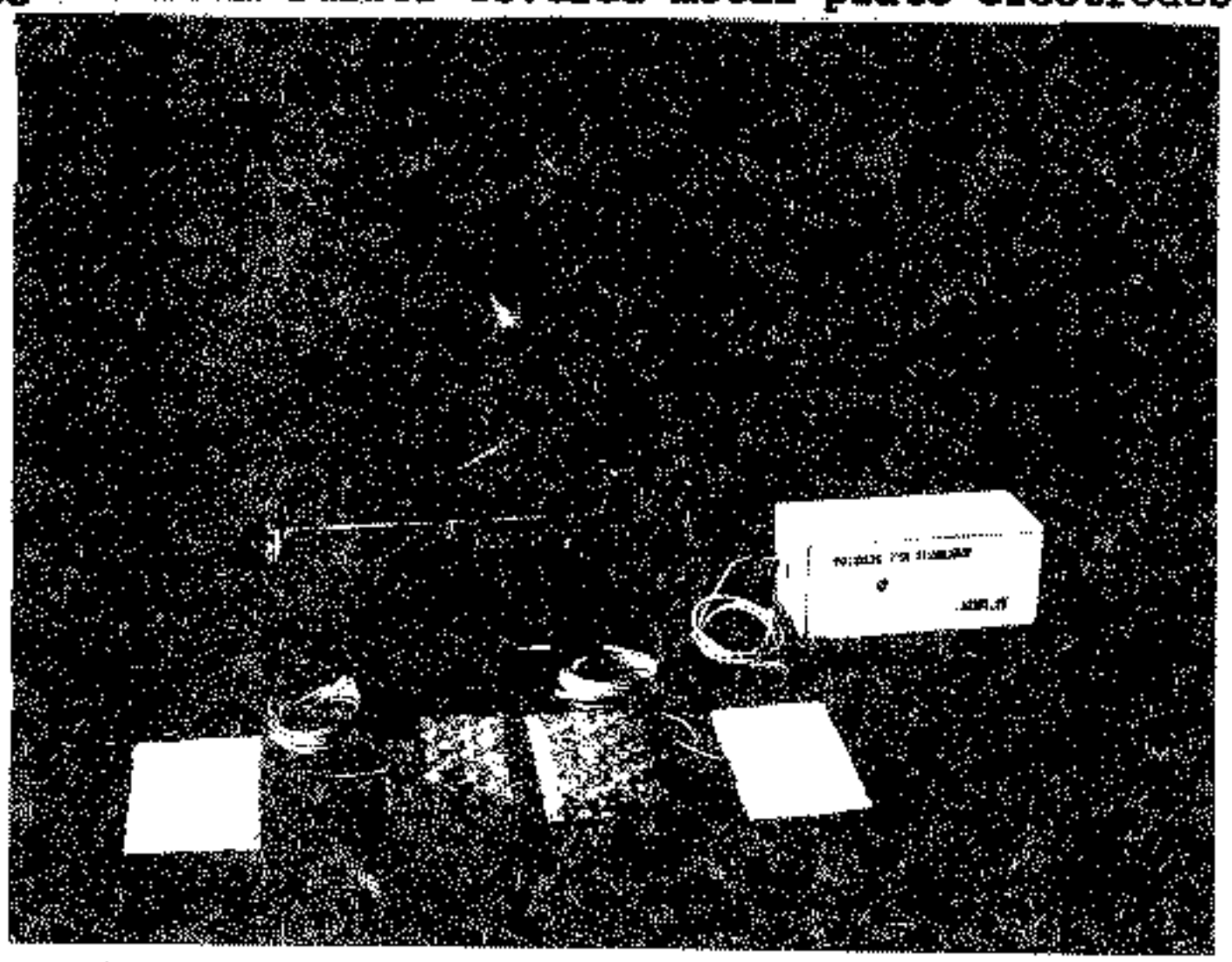

Fig. 1. Two-channel stimulator for exercising of atrophied muscles and standing in complete paraplegic patients.

The electrode size was between 25 and 50 cm^2. For electrodes fixing velcro bands or Medtronic adhesive tapes were used. Voltage output stimulators were used to avoid skin burning, which can eventually come up as a consequence of loosened or dried out electrodes if current output stimulators are used. Rectangular stimulation pulses of 0.3 ms pulse duration were used and 20 Hz stimulation frequency applied.

As the patients begin with the FES program several months after the injury their muscles are already atrophied because of the disuse. Therefore, muscle strengthening (5) is to be the first step in the rehabilitation of paraplegic patients with FES. The stimulation amplitude is set in order to obtain a good muscle contraction. A program of 4

duration of stimulation train and 8 s of pause was selected. Isotonic exercising was used, it being more effective than isometric. The knee joint torque measurements at different stimulation amplitudes were taken every week during the muscle strengthening program .

FES standing

For rising from the wheel-chair a complete paraplegic patient needs a solid support at least for one arm. Such solid support can be provided by a piece of furniture at his home. With the other hand he must hold a crutch. In the two-channel stimulator intended for patient's home use a delay was provided between switch-on and beginning of stimulation. In this way patient can first turn on the stimulator and than grasp the support. A special supporting frame was built for patient's daily standing exercise at home (Fig. 2). The two-channel stimulator is attached to the patient's belt. During 30-60 min of standing patient can look through the window (on his right), talk with visitors or read a book on a special holder which can be attached to the wall. A delay between turning off the stimulator and the end of stimulation permits secure sitting-down.

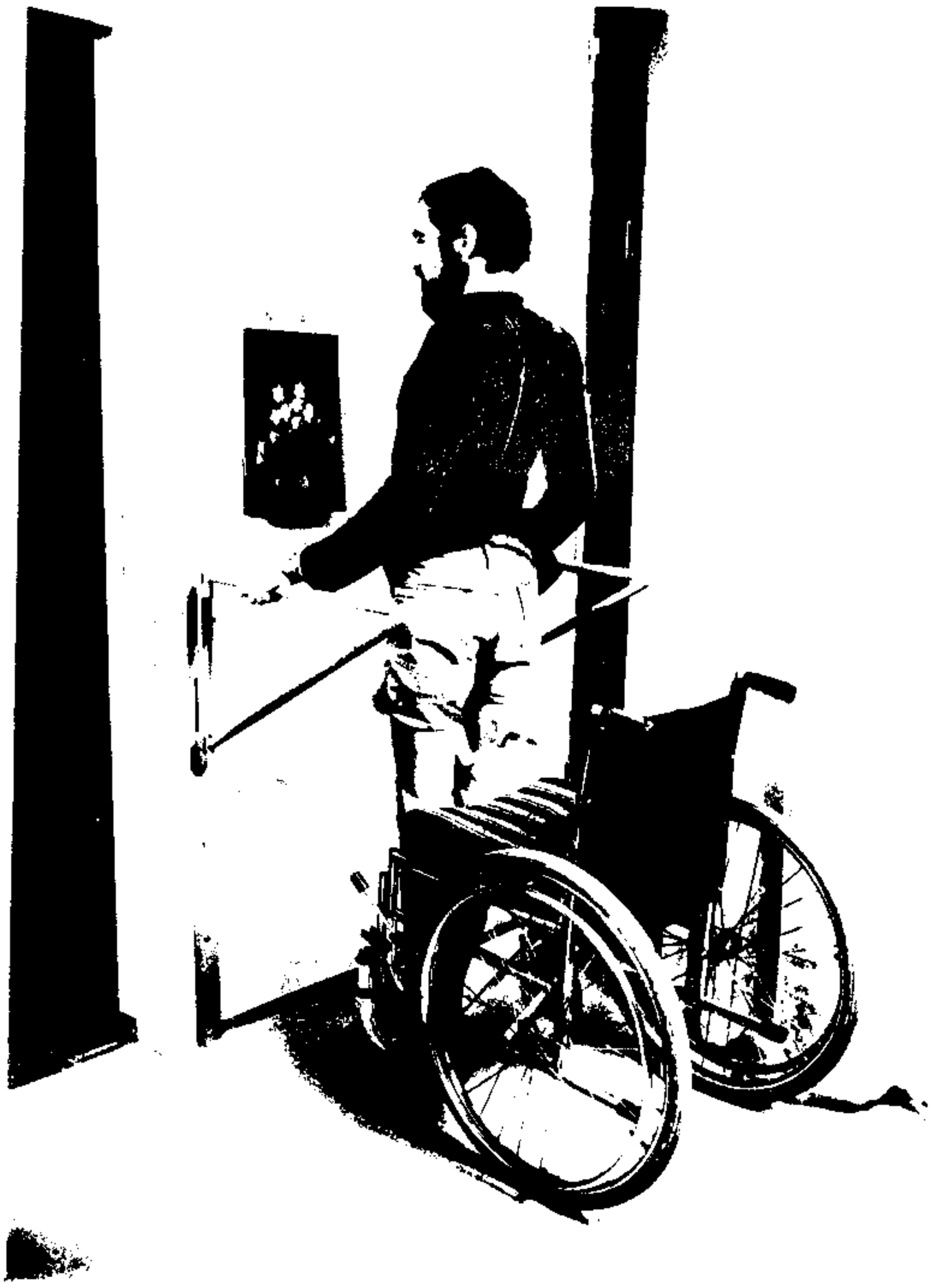

Fig. 2. Paraplegic patient standing with the help of electrical stimulator at his home.

Standing at any location is provided by a special wheel-chair attached collapsible supporting frame (Fig. 3). The supporting frame slips into the holders for the leg supports of the

wheel-chair. The frame is constructed from alloy-steel and it is enough rigid. When it is collapsed it does not disturb the normal use of the wheel-chair. The height of the support can be adjusted according to the patient's needs. All these operations, including the storing in the car, can be performed by the patient without any external help.

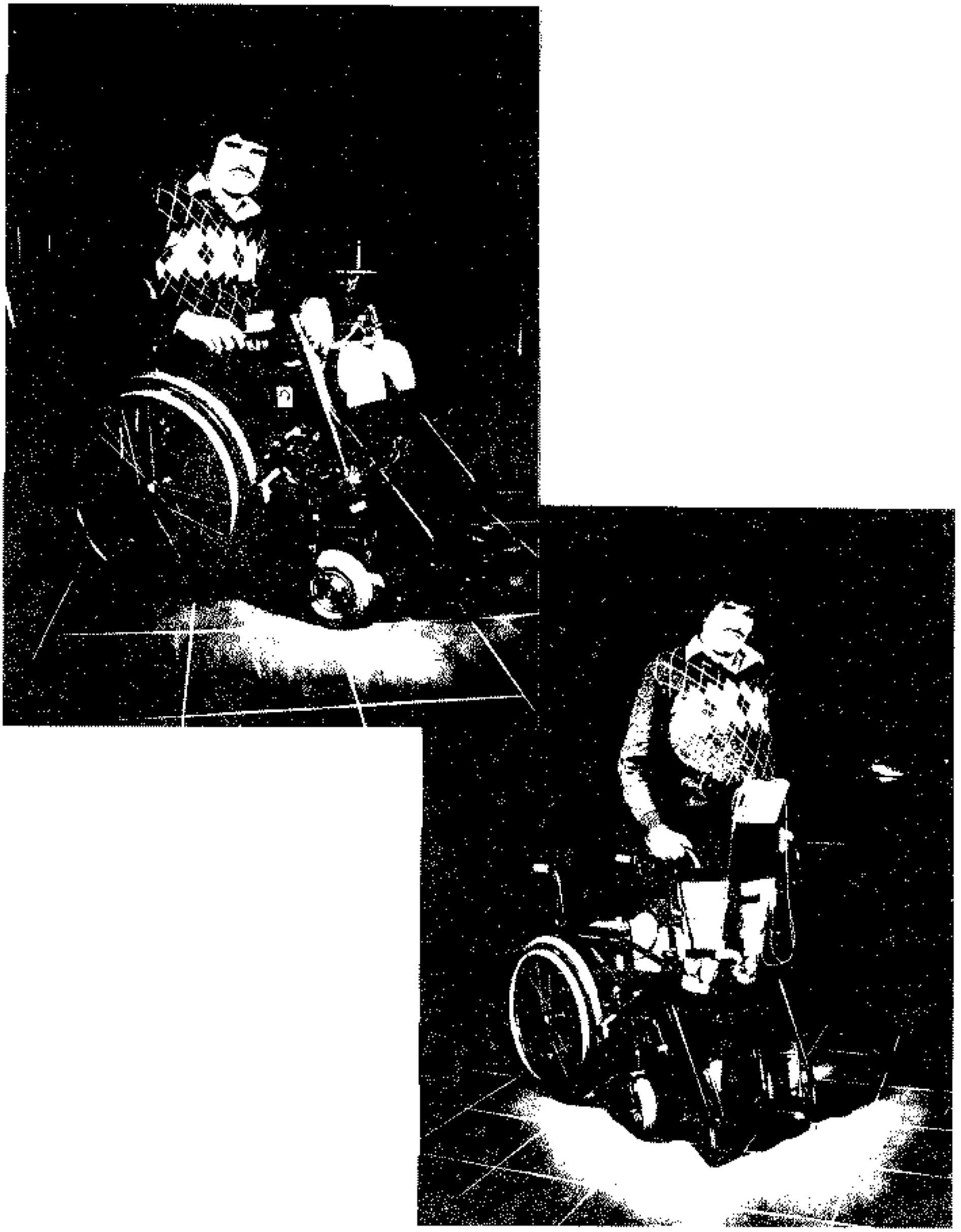

Fig. 3. Wheel-chair attached supporting frame while collapsed (a) and patient standing with it's help (b).

To gain the confidence into the FES assisted standing the biofeedback learning was introduced. The precision pendulum was used as an angle transducer in equilibrium bio-feedback (Fig. 4). The signal from the transducer is first amplified and then split into the positive and negative part representing forward and backward swinging of the body. The voltage proportional to the angle is transformed into the frequency, which can be heard from two loud-speakers.

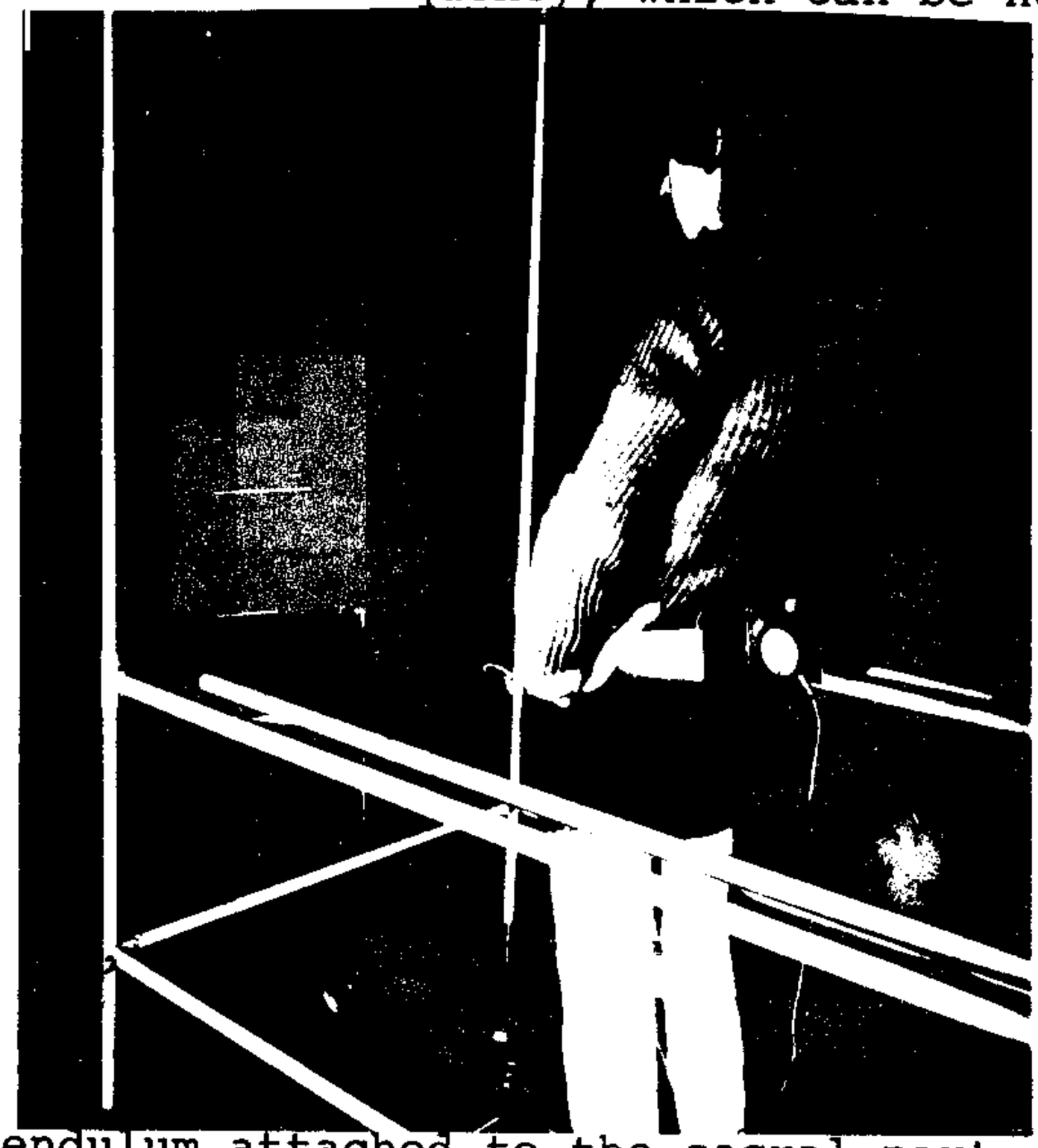

Fig. 4. Precision pendulum attached to the sacral part of paraplegic patient's trunk.

The precision pendulum is attached to the sacral part of the patient's body. The loud-speakers are positioned in front and behind him. When the patient is leaning forward the loud-speaker in front of patient is loud. The success of such a training was estimated by measuring the time of standing without the arm support. After five days of training (half an hour per day) this time increased e.g. from 1.4 s to 3.5 s. The time of standing without the arm support is well correlated to the status of the preserved trunk muscles.

Results

Nine patients participated in the described FES program. Two of them did not get complete the program so no definite conclusions can be made about them. All the patients except one (C-7) had thoracic spinal cord lesions. Three of the patients were few years after the injury while the rest were introduced to the program several months after the accident. After leaving the Rehabilitation Institute the two-channel FES unit was given to all seven patients, although three of them were able to stand for few minutes only. The fatigue of electrically stimulated muscles was in these three patients noticeable in spite of low stimulation frequency. One of these patients reported about a significant decrease of blood pressure from 190/120 to normal after the cyclical stimulation of lower extre-

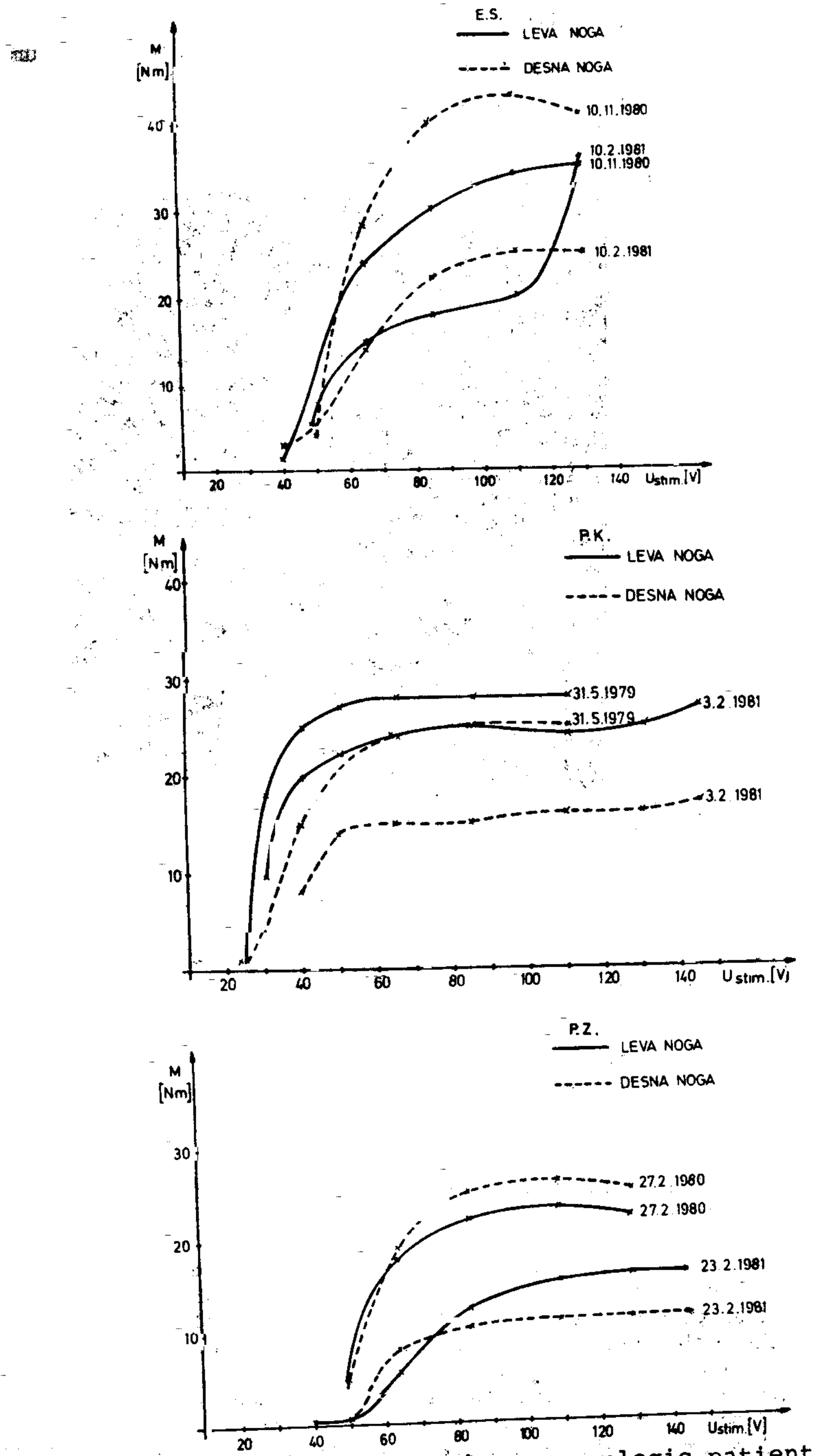

Fig. 5. Knee joint torque in three paraplegic patients at and after the release from the Rehabilitation Institute.

mities . One of the patients who was able to stand for more than one hour was exercising only twice a week and standing once a week during the winter time. The reason is in the underwear which makes the mounting of the electrodes inconvenient. He also reported about the improvement of spasticity and more regular defecations during the day when he is stimulating his legs. During the summer time, when wearing short pants, he is using stimulator every day. The patient did not want to use the wheel-chair attached supporting frame. One of the patients, who is also able to stand with FES for very long periods, did not want to accept the stimulator or the calipers. Although he is very spastic, he reported that spasticity doesn't represent a major problem to him. He has no problems with functioning of the internal organs. One year after the accident patient has noticeable contractures in all three joints of lower extremities. The remaining two patients are enthousiastic about the use of FES. In Fig. 5 the knee joint torques versus the stimulation amplitude of three paraplegic patients, who are successful in standing, are presented. They were measured at the release from the Rehabilitation Institute and at the first control examination. It can be noticed that the knee joint torque was somewhat lessened after the release of the patients.

Conclusions

Except the obvious upper motor neuron lesion the following criteria for patients selection were taken into account: patient's agreement, good psycho-physical condition, no pressure sores, no contractures, age, interest for collaboration, no heterotropic ossifications, no thrombophlebitis. Regarding the presented results in nine complete paraplegic patients it seems that our screening is not sufficient. All of the chosen patients were not the candidates for standing. In further investigations it must be found out whether the reasons for successful standing lie in biomechanical or in neurophysiological conditions of spinal cord injured patients.

Acknowledgements

This investigation was supported in part by Research Grant 23-P-59231/F from the National Institute of Handicapped Research, Department of Education, Washington, D.C., and the Slovene Research Council, Ljubljana, Yugoslavia.

References

(1) Kralj, A., Bajd, T. and Turk, R., "Electrical Stimulation Providing Functional Use of Paraplegic Patient Muscles", Medical Progress through Technology, pp. 3-9, 7, 1980.

(2) Bajd, T., Kralj, A., Šega, J., Turk, R., Benko, H. and Strojnik, P., "Two-Channel Electrical Stimulator Providing Standing of Paraplegic Patients", Physical Therapy,Apr.1980

(3) Kralj, A. and Grobelnik, S., "Functional Electrical Stimulation - a New Hope for Paraplegic Patients", Bull. Prosthet. Res., pp. 75-102, Fall, 1973.

(4) Bajd, T., Kralj, A. and Turk, R., "Standing-up of Healthy Subject and Paraplegic Patient", J.Biomechanics (sent for publication).

(5) Kralj, A., Bajd, T. and Turk, R., "The Influence of Electrical Stimulation on Muscle Strength and Fatigue in Paraplegia", Proc. of International Conference on Rehabilitation on Engineering, Toronto, Canada, pp. 223-226, 1980.