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STANDING BY FES IN PARAPLEGIC PATIENTS

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ABSTRACT - The article reports the use of electrical stimulation to provide paraplegic patients with complete lesions of the spinal cord the ability to maintain a standing position. The patients with similar etiologies were found to not perform the prolonged standing with the same success. Their maximal standing times are ranging from few minutes to up to more than one hour. The aim of the investigation was to determine the differences between successful and unsuccessful patients by measuring isometric knee joint torques, knee extensors spasticity and different biomechanical parameters during standing.

INTRODUCTION

Functional electrical stimulation of extremities has found three main applications in the rehabilitation of complete paraplegic patients (1). Continuous two-channel electrical stimulation of both knee extensors provides standing in spinal cord injured patients (2). The same two-channel stimulation enables also rising from sitting to the standing position (3). With the help of four-channel stimulation reciprocal pattern of simple ambulation was synthesized (4,5).

The candidates for FES treatment are patients with spastic paraplegia from complete spinal cord lesion. The indications for patient selection include (5): upper motor neuron lesion, positive results of FES restrengthening program, no joint contractures, no major skin problems, normal balance sensation, good physical, mental and emotional condition and good cooperation. The contraindications for FES are the following: osteoporosis, ossifications of joints, peripheral lesion of main leg muscles, severe atrophy of muscles, pressure sores, obesity, very severe spasticity and inadequate sitting balance.

While selecting the patients according to the described indications we have found out that all complete paraplegic patients are not performing the standing exercise with the same success. Some of the patients are able to stand for one hour or even for several hours while some of them can remain in erect standing posture only for few minutes. The aim of this investigation was to determine the differences between both groups of patients by measuring isometric knee joint torque, knee extensors spasticity and different biomechanical parameters during standing.

METHODS

Eight patients were chosen for the study. Their general data are listed in Table 1. All of them have successfully completed the FES restrengthening program of atrophied paralyzed knee extensors. Seven of them (except patient N.M.) had the two-channel stimulator for muscle exercise and standing at home. The candidates for FES standing are mostly the patients with the spinal cord lesion at the thoracic level. In the group of the eight patients

TABLE 1.

Initials	Sex	Age	SCI level	Time past injury	Accident	Time of FES training
C.B.	M	19	T-3	2y.5 m.	MVA	1y.9m.
S.K.	M	31	T-11	9y.10m.	MVA	3m.
V.I.	M	20	T-11	11m.	fall	9m.
S.J.	M	50	T-5	3y.3m.	GSW	5m.
C.B.	M	46	C-6	4y.5m.	fall	1y.
N.M.	M	26	T-8	5y.5m.	MVA	1,5m.
J.H.	M	20	T-5	1y.7m.	MVA	1y.5m.
S.M.	M	26	T-5,6	2y.5m.	MVA	2y.

only one patient was quadriplegic. He could not raise from the sitting to the standing position independently while standing-up did not represent any problem for all paraplegic patients. In Table I MVA means motor vehicle accident and GSW gun shot wound.

Isometric knee joint torque was assessed by a special measuring system transforming the moment into the voltage via the strain-gauge transducers. The device, into which the lower leg must be firmly fixed, was designed and built in our laboratory at Faculty of Electrical Engineering. During the measurement, the patients were in the sitting position.

Spasticity was tested with the pendulum test (6). Spasticity of the knee extensor muscles was tested by placing the patient on a tilt table in supine position with both legs bent over the edge hanging free at the knee. The examiner grasped the foot and brought one leg to a horizontal position. The limb was allowed to fall freely while recording knee angle with an electrogoniometer. The level of spasticity was evaluated from the initial drop of the leg. A normalized relaxation index R was defined as the ratio between the amplitude of the first swing and the difference between the starting and resting angle. $R \geqslant 1$ signifies a nonspastic limb whereas $R < 1$ quantifies various degrees of spasticity. The pendulum tests were performed ten times, one after

another. The time elapsed between two successive tests was 30 seconds. To quantify this repetitive testing the average value of ten relaxation indices was calculated and denoted as R_{10}.

The posture performance was assessed through force plate measurements and photography. The vertical and the horizontal components of the reaction force were recorded during one minute of standing with both legs, right leg only and left leg only on the force plate. The patients were standing with the help of arm support. White markers have been attached to the approximate centers of hip, knee and ankle joint rotation. By the help of simultaneous photographic recording and force plate measurement, hip, knee and ankle moments during standing have been calculated.

Fig. 1. Paraplegic patients S.K. (left) and S.M. (right) during biomechanical measurement of the posture

RESULTS

The paraplegic patients were standing by the help of two-channel electrical stimulator and arm support. Continuous FES caused knee extensor muscles to contract, which maintained the knee joints in extension and thus allowed standing. Surface electrical stimulation of knee extensor muscles was delivered through large (6x4 cm) stainless steel sheet-metal electrodes covered with water-soaked foam rubber. The electrical pulses used were rectangular and monophasic. A stimulation frequency of 20 Hz, a pulse duration of 0.3 ms, and a stimulation amplitude up to 100 V were used.

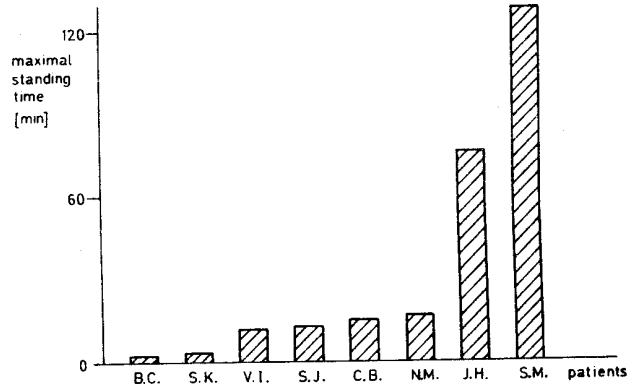


Fig. 2. Maximal standing times in eight paraplegic patients

In Fig. 2 the maximal standing times of the eight paraplegic patients are presented. They are ranging from as short as few minutes up to more than two hours. The patients are ranged on the horizontal axis from the left to the right regarding the successfulness of standing. The same order will be kept also in the rest of the diagrams.

Maximal isometric knee torques are displayed in Fig. 3. Before the FES restrengthening program the patients can usually not develop more than 10 Nm. After the training with cyclic electrical stimulation 50 up to 100 Nm can be obtained. (Healthy

subjects can voluntarily develop over 200 Nm). From the Fig.3 it can be concluded that all the patients successfully completed the restrengthening program so that their maximal isometric moments were adequate to accomplish the FES assisted locomotion activities. According to our experiences patients with less than 50 Nm of knee torque are not candidates for FES rehabilitation approach.

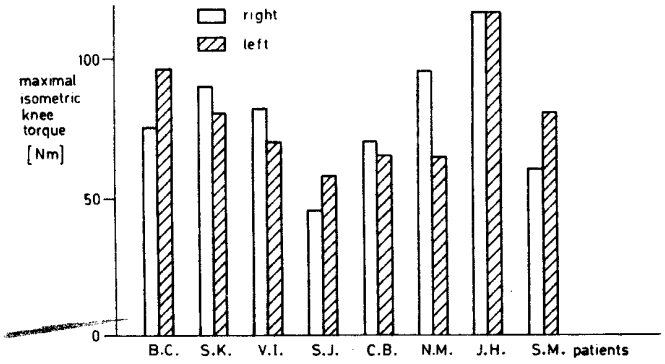


Fig. 3. Maximal isometric knee torques of right and left extremity in eight paraplegic patients

In Fig.4 the relaxation indices R and R_{10} describing the spasticity level in eight paraplegic patients are shown. The two patients (J.H. and S.M.), who are performing the standing exercise the most successfully, demonstrate only slight spasticity. In the contrary, spasticity (specially in the trunk muscles) prevents adequately aligned standing in patient S.K. (Fig. 1). The relaxation indices in Fig. 4 are represented by average values of three measurements taken at three different days.

The biomechanical measurement of the posture parameters was not performed with the patient C.B. whose standing was rather insecure and shaky. It can be noticed from the Fig. 5 that the knee joint torques during standing are almost in all patients rather small. The positive torque is acting in the clockwise direction when the patient is standing as shown in Fig. 1. It is interesting

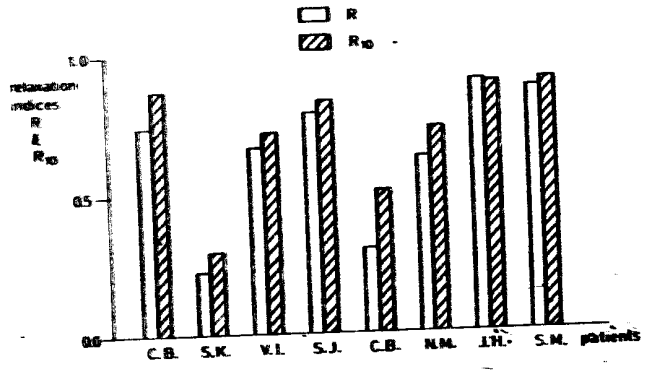
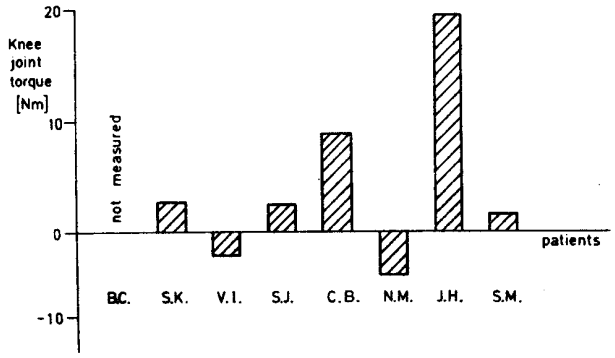


Fig. 4. Relaxation indices describing the spasticity level in eight paraplegic patients

to notice that the values of the ankle joint torques are high while standing. An important observation is that the lowest ankle joint torques occur in both patients who are the most successful in prolonged standing (J.H. and S.M.).

Horizontal reaction forces (in satittal plane) display zero values during unsupported standing of healthy subjects. The minimal horizontal reaction forces were found in the best two patients J.H. and S.M. (Fig. 6). This means that their arm support is low during standing. Small horizontal reaction forces were found also in patients S.J. and C.B. Both have stimulators at home and are now (half a year after the measurement) able to stand for at least one hour.

By measuring the vertical reaction forces we have found out that there is a good symmetry between right and left leg loading in the best two patients. In patient S.K. the symmetry is not adequate. It can be also noticed that the patient is compensating a considerable part of his body weight by the arm support.



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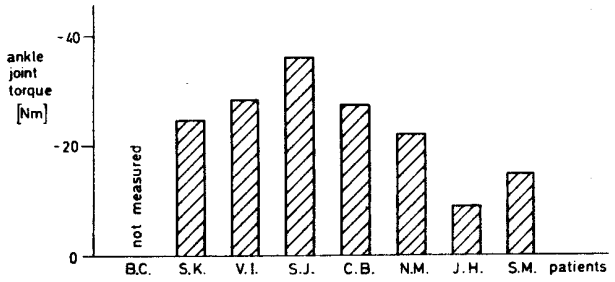

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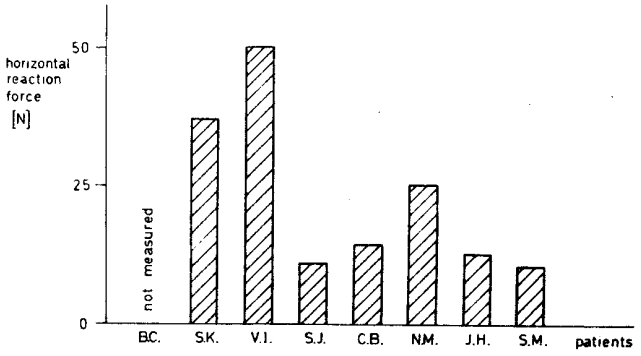
Fig. 5. Knee and ankle joint torques during standing



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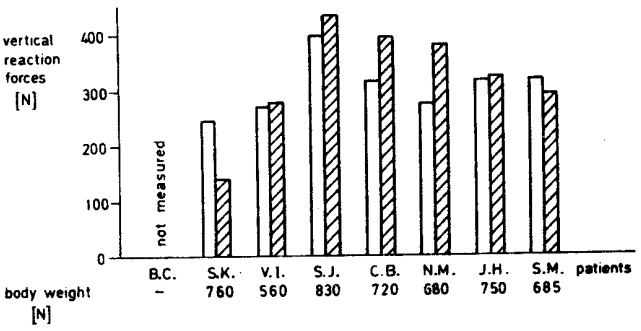

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Fig. 6. Horizontal and vertical reaction forces during standing

DISCUSSION

The advantages of standing are that it can help prevent decubiti, improve function of the bladder and other internal organs and provide better blood flow in paralyzed parts of the body. In addition, standing with FES prevents muscle atrophy, reduces spasticity, prevents contractures and preserves bone condition.

Functional standing at any location is provided by a special wheel-chair attached collapsible supporting frame (3). In this way paraplegic patient can get an object out of the reach from the wheelchair.

The measurements of isometric knee torques did not provide conclusive results regarding the successfulness of standing by the help of FES. Isometric knee torque represents necessary but not sufficient condition for successful standing.

Also interesting are the results of spasticity testing. It was initially expected that spasticity helps at standing. It is well known that some patients by pinching themselves can provoke extension spasms. By the help of these spasms the patients can sometimes stand for few minutes. In the contrary, the best candidates for FES enabled standing show only slight spasticity.

The most important seem to be the biomechanical parameters of posture. Well aligned standing with low values of torques in all three joints is a prerequisite for successful standing in paraplegic patients. The ankle joint torque was found to be the most significant parameter as this joint represents the contact of standing body with the ground. Ankle joint stabilization by mechanical bracing may prolong the maximal standing time in complete paraplegic patients. It was already shown (7) that paraplegic patients can stand by the stimulation of ankle joint plantar flexors only. Switching between stimulation of knee extensors and ankle plantar flexors can overcome the fatiguing of the stimulated muscles and considerably improve the maximal standing time.

In conclusion we can say also that improved methods of measurement and analysis may bring new progress in the rehabilitation of the paraplegic patients. With the help of real time measurement of joint torques for example we could teach the patients how

to attain the proper, well aligned posture. Advanced methods of measurement will also help to make FES assisted locomotion in paraplegic patients more secure, fast and efficient.

ACKNOWLEDGEMENT

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