From the wheelchair to walking with the aid of an eight channel stimulation system: a case study

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Abstract

Functional Electrical Stimulation (FES) is useable to restore in part the lost leg function of paraplegic patients. For this purpose an eight channel stimulation system was developed to activate via standard hydrogel surface electrodes quadriceps and gluteus muscles, peroneal reflex and either adductor muscles or any other muscle group according to patients individual needs.

In the scope of a clinical trial ten paraplegic patients were trained to achieve standing up and walking by means of FES. This paper describes the rehabilitation process of one subject from the beginning to FES supported walking over a distance of 5 meters.

1. INTRODUCTION

In 1792 Luigi Galvani demonstrated that electric pulses are able to stimulate nerves provoking a contraction of adjacent muscles. Based on this early findings Adrian Kantrowitz attached in 1960 electrodes to the skin of a person with paraplegia, applied electric current and demonstrated standing up with own muscle power [1].

Since then different approaches were used to restore leg functionality. Some groups use implantable electrodes and pulse generator [2], some use implanted electrodes and an external pulse generator [3] and others use skin attached electrodes with an external stimulator [4]. Each approach has its advantages and disadvantages. The Vienna group uses surface stimulation to avoid the implanting procedure and give the patient the opportunity to join the FES program instantly.

Surface stimulation faces the draw back of a small number of accessible muscle groups due to the electrode size and for practicability reasons (each muscle requires two electrodes to be put on and off each session) and reduced selectivity also due to electrode size and placement.

The idea behind the Vienna stimulation system is to partially compensate these drawbacks by providing a wide range of stimulation parameter variability in conjunction with a parameter optimisation protocol [5,6].

In a clinical trial according to EN ISO 14155 the stimulation system and rehabilitation strategy should be tested and optimised.

In the following the results observed in one patient are described.

2. METHODS

2.1. Patient

The introduced patient is male, 48 years old, 175 cm high and has 95kg. He suffers from complete paraplegia (ASIA A, Th8) since end of 2001 and entered after a faithful examination the FES study in November 2003.

2.2. Pre study training

The FES rehabilitation started with a muscle strengthening program. Tetanic contractions in a sitting position, lying position or sitting position with extended legs in a 3.5 seconds on and 4.5 seconds off regime were applied according to table 1. Stimulation parameters were: biphasic constant current impulses, 0.3+0.3ms, 30Hz, amplitude adjusted to achieve strong contractions. Quadriceps and gluteus muscles were trained. After week 6 quadriceps training with weights was included on 2 days of the week. The weight was chosen that a knee extension was just possible.

After 3 month knee torque was measured with a custom built device. Knee angle was 90°,

Week	Duration / Rest [min]	Repe-titions	Days/ week	Muscle
1	3 / 1	3	6	G+Q
2	3 / 1	4	6	G+Q
3-4	4 / 1	4	6	G+Q
5-6	5 / 1	4	6	G+Q
7-12	5 / 1	5	6	G
7-12	5 / 1	5	4	Q
7-12	12 x w. weights / 2	5	2	Q

Table1: Training protocol f. muscle strengthening (G: gluteus muscles, Q: quad. muscles)

biphasic constant voltage impulses (0.5+0.5ms), 30Hz.

2.3. Standing up

After a sufficient knee torque (>30Nm) could be achieved on each leg the patient started to train standing up, standing and sitting down. As supporting device a parallel bar was used. In this stage the home training program was modified. Three times per week the patient had to practise standing up, standing and sitting down. The manoeuvre had to be performed 5-10 times; 3-5 minutes rest in between. Standing had to be aborted as soon as muscle fatigue was observed. On three other days a muscle strengthening program in sitting position with 5kg weights mounted around the ankles was performed for one hour with 20 repetitions in 4-5 trains. Two times each week tetanic contractions (2s on, 4s off) for 10 minutes with 5 minutes rest had to be performed 4 times in a row. Two times per week standing in the stand up table for 1 hour was included.

2.3. Walking

After the patient had a good balance and could take an upright posture stepping was started. First in parallel bars and as soon as the patient felt save with a rollator. In the home trainings program practising standing was replaced with walking training if an assistant was present.

2.4. Training in the clinic

Each month the patient came to the clinic for training and equipment check. After a muscle warming up electrode placement for peroneal reflex was checked and stimulation amplitude for titanic contraction was, if necessary, adjusted. Then the patient started to practise under supervision of the therapist. Stimulation parameters were optimised according to the abilities of the patient. As soon as the parameter adaptation was finished consecutive trials were made. The heart rate was monitored with a standard heart rate monitor (Polar, Vantage NV). A trial started as soon as the heart rate was below 100 beats per minute. The patient stood up, corrected his posture, the stop watch was started and the patient walked until he was exhausted or muscle fatigue was recognised. The covered distance, the related time (duration) and the number of steps were recorded. After the stimulation was turned off the heart rate was noted.

2.5. Electrode placement

A pair of hydrogel electrodes each was placed over quadriceps muscles and gluteus muscles, below the knee near peroneal nerve to elicit flexion reflex and on the inner side of the thigh to access adductor muscles.

2.6. Stimulation system

The eight channel stimulator is mounted on a belt and worn around the waist. It consists of two four channel stimulation modules and one main module housing the batteries and various electronic components responsible for the communication with peripheral equipment. A Pocket PC (Comapq, Ipaq Model 3950, HP, Houston, Texas, USA) handles wireless LAN communication, database management (Microsoft SQL Server 2000 Windows CE Edition) and provides the graphical user interface. A wireless remote control (433MHz) can be mounted on either the parallel bar or the rollator and allows to toggle the stimulation task (standing up, walking, and sitting down) and to trigger the stimulation.

In the clinic the Pocket PC is bypassed and control over the stimulator is taken via wireless LAN from a PC software package. Stimulation parameters are edited on the PC. As soon as the training protocols and functional tasks are finished the data are transferred for home use using database replication between PocketPC and PC.

A more detailed description of the stimulation equipment can be found at [5].

3. RESULTS

After three month muscle strengthening knee torque was 37.4 Nm on the right leg and 54.3 Nm on the left leg. Both values at a stimulation amplitude of 60 V peak to peak.

The results from the walking training are summarised in table 2. Month 0 marks the first session were walking was performed without major assistance.

Time [month]	Distance [m]	Time step to step [s]	Stride length [cm]	Heart rate change [bpm]
0	3.1 ± 0.4	7.1 ± 1.7	18 ± 1.6	22 ± 17.6
2	3.2 ± 1.2	7.7 ± 0.3	16 ± 4.1	23 ± 10.6
4	4.4 ± 0.4	4.2 ± 0.4	21 ± 1.1	20 ± 09.9
5	4.0 ± 1.0	4.5 ± 0.8	19 ± 1.6	38 ± 18.4
6	5.0 ± 0.8	4.2 ± 0.2	22 ± 3.7	48 ± 12.8
7	4.6 ± 0.2	3.1 ± 0.1	20 ± 1.0	27 ± 11.5

Table 2: Results of FES walking trials. All values are mean±SD.

The stimulation pattern was changed during the first 4 month according to the progress of the patient. After this time only very little changes of the stimulation amplitudes were necessary.

For standing up first the quadriceps muscles were activated with a 0.1s lasting ramp up to 41Vpp. Gluteus followed with a delay of 0.1s and ramped up to 40Vpp. After two seconds the quadriceps amplitude was reduced to 35Vpp to minimize fatigue. Quadriceps muscles were stimulated with pulse with of 1+1ms, all other muscles with 0.6+0.6ms. Stimulation frequency was 26Hz except for standing up where 35Hz for the quadriceps improved the dynamics of the movement. For stepping gluteus and quadriceps muscles were turned off for 0.8s while peroneus stimulation was activated. A significant advancement of flexion reflex was achieved by raising the stimulation frequency to 120Hz. Activation of adductors during the swing phase improved the leg movement.

4. DISCUSSION AND CONCLUSIONS

An eight channel stimulation system was used to achieve standing up and walking in a Th8 paraplegic subject. Three month of an intensive muscle training were sufficient to achieve knee torque >30 Nm.

The walking distance until the patient was exhausted during one trial could be improved during the first four month of walking training from roughly 3m to 5m, the stride length from 18cm to 22cm while the time from step to step decreased from 7.5s to 3s. The latter demonstrates the improved balance and increased abilities to coordinate body movement with the stimulation. The stride length could be elongated even more but the patient was advised to keep his steps short for safety reasons. Long steps can easily lead to loss of balance.

Disappointing is the short walking distance and that no improvement was observed during the last months. An explanation could be found in the posture of the patient. He cannot achieve a complete upright position due to a light contracture in the hip, causing a higher load on the arms which is borne with continuous contraction of the upper body muscles resulting in a reduced endurance.

To overcome this problem a special stretching program for the hip was added to the home trainings regime. Additionally the stimulation program was changed to train the muscles towards fatigue resistance.

The body weight seems also to play a major role. Slim patients can walk much further, in our study up to 100m.

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