Clinical application of an eight channel stimulation system for mobilization of paraplegic patients: First results

Bijak M 1, Rakos M 2, Hofer C 3, Mayr W 1, Strohhofer M 3, Raschka D 3, Kern H 3

1 Department of Biomedical Engineering and Physics, Medical University of Vienna, Austria
2 Otto Bock Healthcare Products GmbH, Vienna, Austria
3 Department of Physical Medicine and Rehabilitation, Wilhelminenspital, Vienna, Austria

Email: manfred.bijak@univie.ac.at
Website: www.bmtp.akh-wien.ac.at/bmt/home.htm

Abstract

Seven paraplegics with experience in FES usage and five paraplegics new to FES volunteered to test a newly developed eight channel stimulation system. The goal was to discover the influence of various stimulation parameters on the gait quality. As additional task the usability should be simplified as much as possible. Commercially available hydrogel electrodes were attached to quadriceps and gluteus muscles for hip and knee extension, peroneal nerve to elicit flexion reflex and on adductor muscles. All patients were positive about the handling of the stimulation system. Especially the wireless crutch or walker mounted remote control was highly approved. Nevertheless the stimulation modules have to be further miniaturized. First results demonstrate the importance of an amplitude ramp during stimulation onset resulting in a smoother and more “natural” movement. For an adequate step length and consistent stepping pattern optimisation of the timing of peroneal stimulation switch-off and quadriceps stimulation activation is necessary. Activation of the adductor muscles lead to a better knee trajectory during standing up and better leg movement during the swing phase.

1 Introduction

In 1961 Adrian Kantrowitz demonstrated for the first time electrical induced standing in paraplegic patients with intact lower motor neuron by stimulating quadriceps and gluteus muscles [1].

During the following 40 years this approach to restore leg functions in paraplegic patients did not change very much.

Several groups use implantable stimulators to activate the leg muscles. The advantages of an implantable system in short are the high number of muscles that can be activated (only limited by the number of output channels), the achievable selectivity (by positioning the electrodes close to the motor points) and always availability of the system [2,3]. The major drawback of implanted systems is the necessary surgical intervention to implant the stimulator, the electrode leads and the electrodes at the nerve or motor point, associated with a longer stay in the hospital.

Other groups still use surface electrodes to achieve hip and knee extension. For stepping/walking additional electrodes are placed close to the common peroneal nerve to elicit the withdrawal reflex for a flexion in hip, knee and ankle [4][5]. Such a surface stimulation system can be prescribed and applied at any time and does not require a stay in the hospital. Patients complete their training under supervision of doctors and therapists on an ambulatory basis. As major drawbacks can be named firstly the always required set up time before usage (attach electrodes, hide cables, connect device, check for proper electrode placement) and secondly the unselective stimulation: Strong contractions require larger electrodes resulting in unwanted co-activation of close-by muscles, deeper muscle groups can not be reached without activating the superficial muscles.

Figure 1: Two four channels stimulation modules, control device holding batteries and communication management and electrode connectors

These deliberations explain the limited outcome of restoring leg movement with surface electrodes.
Our approach to get better results with standard electrode application is stimulation parameter optimization.

Figure 2: Components from figure 1 mounted in a belt to be worn around the waist

2 Methods

An eight channel stimulation system (currently subject of a cooperation between the Medical University Vienna and Otto Bock) was used in this study [5]. The system consists of two four channel stimulation modules – one for each leg – and one module holding the batteries and the components for bus management and wireless communication with patients input devices, mounted on the crutch or on the walker (Fig. 1).

A Pocket PC (Compaq, Ipaq Model 3950, HP, Houston, Texas, USA) is integrated in the system as database manager (data upload, download, synchronisation), for the stimulation management and to implement a wireless LAN connection to a PC.

Each output channel is fully isolated to avoid interference with other channels, is completely independent from the other channels in terms of stimulation parameters and can produce complete stimulation sequences autonomously.

All components are integrated in a belt (Figure 2) and worn around the waist (Figure 3).

In the rehabilitation centre a wireless LAN connection is established between the stimulator and a PC. Special software is used to control the stimulator and administer the stimulation parameters. The graphical user interface (GUI) is designed to quickly develop and optimise stimulation sequences for standing up, stepping and sitting down. As soon as the results are satisfying the stimulation sequences are copied to the database on the Pocket PC. Sequences for other tasks like muscle warm up, withdrawal reflex testing and muscle training are also developed, tested and transferred.

Thirteen paraplegics, seven experienced FES users and five new to FES volunteered to participate in a study to test the new stimulation equipment. Hydrogel electrodes were attached to quadriceps, gluteus muscles, adductor muscles and close to common peroneal nerve.

After a muscle warm up of 10 minutes amplitudes were adjusted and electrode positions optimised if necessary. In the following standing up and walking was performed under the supervision of physio therapists while stimulation parameters were varied in amplitude and frequency. Timing was modified to improve the synchronisation of upper body movement with the leg movement.

Figure 3: FES supported standing: Patient wearing 8 channel stimulator, Pocket PC with wireless LAN

The patient activated the stimulation sequence (stand up, step left, step right, sit down) with switches mounted on the walker. Two control strategies were tested: one push button control, triggering the left step by a short keypress and right step by a long keypress and rocker switch mode, triggering steps according to the pressed switch side.

3 Results

All patients were introduced to the new device in two separated one to one and a half hour lasting sessions. No major problems with the handling were reported. Some modifications to the walker mounted control switch for better accessibility with the thumb were necessary. All patients preferred the rocker switch mode.
During standing heavy patients felt well with a steep ramp for stimulation onset (0.2s), slim patients requested slow ramps (up to 0.4s) during standing up. A time delay between quadriceps activation and gluteus activation of 0.2-0.4s was necessary to bring the patient quickly in an upright position after standing up (Figure 4. Top).

![Figure 4: Top: Typical envelope of the biphasic stimulation impulses for standing up. Bottom: Same for one step. X-axes: Time [s], Y-Axes: Peak voltage [V]](image)

During stepping the gluteus timing had no major influence on the gait quality. On the other hand the timing during heel strike when peroneal stimulation is switched off and quadriceps stimulation is turned on was of major influence on the gait quality. 6 patients require 0.0-0.1s where neither peroneal nor quadriceps stimulation is applied, the others require an overlap of 0.1-0.2s (Figure 4. Bottom).

The walking distance until patients were exhausted was 4-60m with a step length of 20-30cm.

4 Discussion and Conclusions

After several trainings sessions and individual parameter optimisation a smooth walking pattern could be achieved in all patients. Of course very important is the permanent input from the physio therapist so that the patient accustoms to a good posture and proper upper body movement in synchronisation with the stimulation.

Nevertheless the short walking distance in some cases is disappointing. It was observed that the exhaustion seems to be mainly caused by the strong contraction of the arms and other upper body musculature the patient used to cling to the walker. More arm support is applied if the patient feels unsafe, makes long steps, has a bad posture (caused by contracture in the hip) and has a higher body weight.

To conclude: An eight channel stimulation system was used in a clinical trial with paraplegic patients. The system was well accepted but further miniaturisation is still required. The available parameter variability is sufficient to get smooth leg movement. Proper supervision of the patient during trainings sessions is mandatory to get best results.

References


Acknowledgements

This project is supported by Forschungsförderungsfonds, Vienna (FFF)