

# Surface stimulation of lower extremities in spastic paraplegic subjects with a PC supported eight channel stimulator

Manfred Bijak<sup>1\*</sup>, Monika Rakos<sup>2</sup>, Christian Hofer<sup>3</sup>, Dietmar Rafolt<sup>1</sup>, Winfried Mayr<sup>1</sup>, Friedrich Russold<sup>1</sup>, Ewald Unger<sup>1</sup>, Maria Strohhofer<sup>3</sup>, Doris Raschka<sup>3</sup>, Helmut Kern<sup>3</sup>

<sup>1</sup>Department of Biomedical Engineering and Physics, University of Vienna

<sup>2</sup>Otto Bock, Vienna, Austria

<sup>3</sup>Department of Physical Medicine and Rehabilitation, Wilhelminenspital, Vienna, Austria

## Introduction

Surface stimulation of lower extremities in paraplegic patients with intact lower motor neuron is an established FES application to provide walker or crutch supported standing up from the wheelchair and walking (stepping) for short distances. Usually m. quadriceps and m. gluteus are stimulated for hip and knee extension while electrodes placed over the peroneal nerve elicit the flexion reflex for a flexion in hip, knee and ankle joint.

Six channel stimulators with constant current or constant voltage outputs are used [1]. According to the required movement (standing up, stepping) stimulation channels are switched on and off. The stimulation intensity is used to optimize the muscle contraction strength to achieve a symmetric movement.



Fig. 1: Patient with 8 channel stimulation system in "Clinical" configuration

Due to the low number of (nonselective) stimulated muscles the observed movement is unnatural and largely independent from the chosen stimulator. Improvement of the gait can be expected from a higher number of channels and electrodes. More electrodes, unfortunately, increase the time for donning and doffing unacceptably.

With the usage of surface electrodes certain limits are quickly reached. Strong contractions require larger electrodes, resulting in unwanted co-activation of nearby muscles. Deeper muscle groups cannot be reached without activating the superficial muscles.

As another approach to improve the gait pattern we concentrate on stimulation parameter optimization. An eight channel surface stimulation equipment with PC interface was developed [2] and included in a clinical trial.

## Material and methods

The stimulation equipment consists of two four channel modules and one module with battery and some circuitry for power management and communication. The modules are interconnected via Inter-Integrated-Circuit-Bus (I2C Bus). Stimulation data is transferred to each channel. When triggered each channel generates a stimulation pattern independently. Biphasic rectangular potential and DC-free pulses are delivered via a transformer to the hydrogel electrodes.

All three devices are mounted on a belt and can be easily worn on the waist. Additionally, the belt stores the connection cables.

The stimulation equipment is controlled either from a Palmtop Computer (Compaq Ipaq, Hewlett-Packard Company, Palo Alto, CA, USA) or a PC.

In the clinic or rehabilitation center where the stimulation sequences are developed and optimized, PC control is used. Therefore the Palmtop Computer is equipped with a wireless LAN card, mounted on suspenders and connected via the RS232 Port with the stimulator (Fig. 1).

A special software package with a graphical user interface permits parameter modification in an easy and clear way. Data are updated via the wireless TCP/IP connection. After stimulation parameter optimization is completed, a selection of stimulation sequences is uploaded to a database on the Palmtop Computer.

The wireless LAN is removed and the Palmtop Computer is put in a pivoting mount on the belt (Fig. 2). The patient can now select a stimulation sequence for standing up, walking and sitting down and adjust the "overall" amplitude for all channels or for single channels. The Palmtop Computer is put in its resting position and is secured with a flap.

A remote control with two push-buttons is mounted on the crutch or walker and allows the patient to change stimulation mode (standing up, walking, and sitting down) and to trigger the stimulation.

Five FES experienced patients volunteered for this study. All of them are using a six channel device for FES walking on a regular basis.

Beginning with the stimulation pattern from the old device we started to smooth the stimulation onset by using ramps. The frequency during the ramp can be modified in 10Hz steps, starting with 25Hz up to 75Hz.

In the next step the timing is changed. At the beginning of the standing up phase the time delay between quadriceps muscle and gluteus muscle, beginning with 0s, is varied in  $\pm 0.2s$  steps to a maximum of 1s. During walking we concentrate in a similar way on the length of peroneal stimulation and the entry of quadriceps and gluteus muscles at the end of the swing phase for a maximum step length (without back swinging of the lifted leg).

A major problem is the quantification of the effects of the parameter alteration. In this first approach we rely on the rating of experienced therapists and the patient. Before a statement is made the patient has stood up with the new modified pattern at least 3 times and walked 10 steps to adapt to the new pattern. Videotaping completes the documentation.

Muscle fatigue would require a stimulation amplitude increase during a session. To avoid an interference of amplitude modification with the alteration of the observed parameters, the amplitude is not raised. Instead a break for recovery is made. If the patient reports the need of a significantly higher arm support the experiments are stopped.



Fig. 2: Patient with 8 channel stimulation system in "Patient use" configuration

In a first approach the fourth channel is used to stimulate adductor muscles for a better knee control (Fig. 2) during standing up and improvement during the swing phase.

#### Results:

The stimulation equipment is reliable and well accepted from the patients. Highly appreciated is the absence of cable connections from the patient-worn equipment to other devices.

The PC software proved to be intuitive and easy to use. Nevertheless, it took four to six sessions under supervision until all features were handled autonomously by initially inexperienced persons.

Despite the experiments being only preliminary, the first results already show the benefit of ramped stimulation onset. A smoother and more convenient movement could be achieved. During sitting down a ramp length of 1s with increased stimulation frequency (40Hz) reduces the impact force when returning to the wheelchair. Peroneus stimulation for 0.6s turned out to be convenient for the swing phase. Stimulation of adductors improved standing up if the electrode position is chosen very carefully (to avoid crosstalk with adjacent muscles).

#### Conclusion

Although the stimulation system is too bulky for convenient every day use it is well accepted by the patients. The four output transformers in each stimulation module that consume the major portion of the case volume are intentionally oversized for this study to have spares in the amplitude. After the study reasonable parameter limits can be defined for a redesign and further miniaturization of the system.

A variation of this amount of parameters requires very cooperative patients. Lots of sessions, mainly due to muscle fatigue, are necessary to find the best parameters. In the future basic stimulation sequences will be provided to reduce the setup (trial and error) time and so the stay in the ambulatory will be kept to a minimum.

#### Acknowledgement

This project is supported by Otto Bock Austria GesmbH.

#### References

- [1] Strojnik, P., Kralj, A., and Ursic, I. Programmed six-channel electrical stimulator for complex stimulation of leg muscles during walking. *IEEE Trans Biomed Eng* 1979;26:112-116.
- [2] Bijak, M., Mayr, W., Rakos, M., Hofer, C., Lanmuller, H., Rafolt, D., Reichel, M., Sauermann, S., Schmutterer, C., Unger, E., Russold, M., and Kern, T. The Vienna functional electrical stimulation system for restoration of walking functions in spastic paraplegia. *Artificial Organs* 2002;26:224-227.

#### Authors Address

Manfred Bijak, Ph.D.  
Dept. of Biomed. Engineering & Physics  
Waehringuer Guertel 18-20/4L  
A-1090 Vienna, Austria  
Tel.: +43-1-40400/1992  
Fax: +43-1-40400/3988  
e-mail: manfred.bijak@univie.ac.at