LONG-TERM SURFACE ELECTROMYOGRAPHY RECORDING SYSTEM

Tepavac[1],D., Swenson[2],J.R., Stenehjem[3],J.

[1]Faculty of Electrical Engineering, Belgrade, YUGOSLAVIA,
[2]University of Utah, School of Medicine, Salt Lake City, Utah, USA,
[3]Sharp Rehabilitation Center, San Diego, California, USA

ABSTRACT

This paper details a method and results of an advanced technique for measuring one component of a spasticity, namely spontaneous muscle activity (SMA). The Surface Electromyography (sEMG) signal was recorded for long periods of time (up to 24 hours) in complete SCI patients, with complete loss of voluntary motor control of the lower extremities as they performed their usual daily activities. A portable microcomputer based device was designed and built for that task. It has a built in analog processing circuit that performs amplification, filtering, rectification and integration of the raw sEMG signal. Integrated sEMG is converted into digital form and stored into microcomputer memory. Following the completion of a 24 hour recording, data was transferred from the microcomputer's memory, to a PC based host computer where additional processing takes place and results are displayed graphically and numerically. Initial results indicate that this approach offers the capacity of providing useful information about the variation of spasticity over time. Ongoing research is exploring the clinical usefulness of this new technique.

KEY WORDS: Electromyography (EMG), Spasticity, microcomputer, Holter monitor.

INTRODUCTION

Spasticity presents an extremely difficult and complex problem in the rehabilitation of patient who suffer from upper motor neuron (UMN) lesions and includes the following phenomena:

(1) increased resistance of skeletal muscles to passive movements
(2) clonus
(3) increased stretch reflex
(4) mass reflexes as a pathological form of motor hyperactivity [12]

Different aspects of quantifying spasticity are presented in numerous papers [1,2,3,4,5,6,7,8,9]. Spasticity may be modified by a number of factors such as the volume of the urine in bladder, presence of decubitus ulcers, patient's position, infections, and preceding exercises. Spasticity fluctuates in time both in intensity and distribution. Methods and tests described in cited literature have generally been technically difficult to implement and they all share one or mwre of these disadvantages:

1. Recording periods are too short.
2. Lack of portability which prevents the patient from performing their daily activities.
3. Lack of reproducibility.

With daily fluctuation of spasticity it would be of vital interest to be able to record spontaneous sEMG in SCI patients, with a compact portable easy to use device, in a manner that would not disrupt their usual daily routine and activities.

Initial efforts in long-term sEMG monitoring began with the use of a modified 2 channel Holter monitor developed by Stenehjem and Swenson [13]. The sEMG of the quadriceps and hamstring muscle in complete paraplegics was amplified using a surface preamplifiers and recorded on a standard audio cassettes. Due to the slow recording speed, using Holter as a recording device resulted in a significant signal loss.

The technique and instrumentation for achieving the goals mentioned above, which eliminates Holter as a recording device, is next discussed.

METHOD AND MATERIALS

To overcome problems inherent in the magnetic tape storage a microcomputer based long-term spasticity recording system was developed (Fig.1 and Fig. 6). It consists of two major subsystems: an analog processing unit and a digital microcomputer based unit. The Analog processing board performs the tasks of amplifying, filtering, rectifying and integrating of the sEMG signal. Active components used are low power consumption JFET and CMOS operational amplifiers with high common mode rejection ratio (CMRR) resulting in very low noise sensitivity. EMG preamplifiers are used for primary amplification between the surface electrodes and the analog board. These preamplifiers have excellent amplification, frequency bandwidth characteristics and noise immunity (CMRR of around 103 dB). Immunity to noise is of vital importance, since the surface EMG signal is in the 5-300 μV range.

Fig. 1: Microcomputer based portable long-term sEMG recording system. Surface EMG signal is amplified, rectified, integrated, converted into digital form and stored into microcomputer memory. After 24 hours, accumulated data is transferred via serial link to the host computer. Data is there further processed and displayed in numerical and graphical form.

Fig. 2 shows the level and shape of the signal through four subsequent stages of processing. The top trace is the output of the preamplifier. Raw sEMG is being amplified around 320 times. The second step is filtering through second order bandpass filter with cutoff frequencies of 12Hz (low) and 1061Hz (high). The third trace shows the signal after it is rectified and further amplified. Output is then fed to the fourth stage where the signal is integrated. This final signal output is proportional to the area below the rectified sEMG curve and therefore represents the Vs (Volt seconds) value of the signal, which closely correlates with muscle activity [11]. The resolution of the portable sEMG recorder is 7.75nVs.

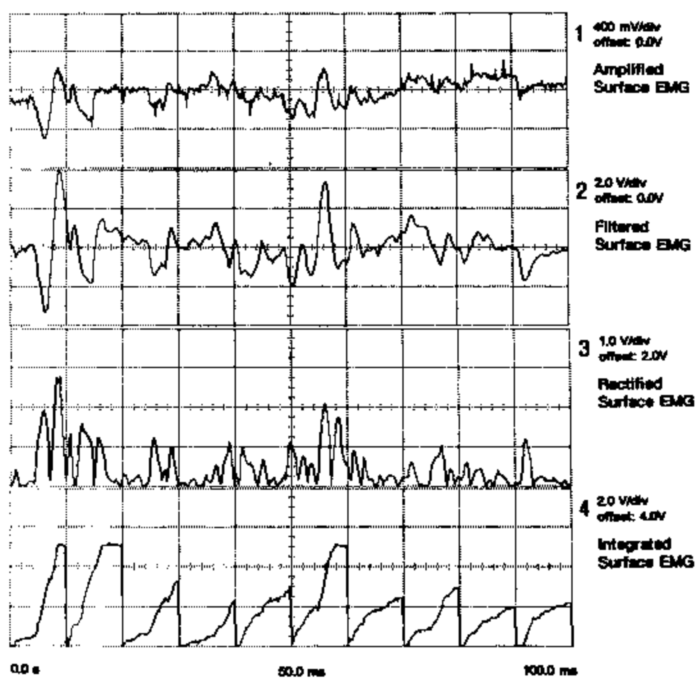

Fig. 2: Shape of the signal on the output of the different stages of analog processing board. Starting from the top trace: amplified raw sEMg signal (output of the preamplifiers), filtered and amplified signal (trace 2), fully rectified signal (trace 3) and integrated sEMG signal (bottom trace). Time on the abscisse is 100ms.

The digital portion of the system responsible for data acquisition, data manipulation and system timing is a CPU board (designed by Meadows [10]), build around the Motorola 68HC11 single-chip microcomputer. It has 2 lines by 16 characters LCD, 4 by 4 digits keyboard,8 A/D inputs, 8 digital inputs, programmable timers, 512 bytes of EEPROM (Electrical Erasable Programmable Read Only Memory), 16 Kb of EPROM, 256 bytes plus 4 times 32 Kb of RAM (Random Access Memory) that gives total of 128 Kb memory and the RS-232 serial interface. The board operates on a 2MHz bus rate.

Dimensions of the portable device are 19 x 10 x 5 cm and it weights approximately 700g (Fig. 6).

A 10 minute procedure for applying circular, self-adhering surface electrodes to the skin was devised. The skin surface over the recording site of the rectus femoris and biceps femoris muscles are shaved and cleansed with alcohol. The ground electrode was applied to the muscle motor point and the active electrodes proximally and distally at a distance of 1 cm from the ground electrode. The electrodes were secured by adhesive plastic film and/or elastic bandages. The sEMG recording device was placed in a bag attached to the wheel chair. Each patient was given a form to note all significant daily activities. These records were used for correlating test results with patients' activities.

Upon completion of a recording, the data stored in the microcomputers memory is transferred via RS-232 serial link to the host computer (IBM-AT compatible) for further processing. This operation takes less than 2 minutes.

A software package, written in C, was developed to support the sEMG recording system and provided serial data transfer, formatted patient data entry, integrated sEMG and histogram plotting, printing processed data on total and partial sEMG activity and graphical data display and manipulation. Floppy discs are used as a media for permanent data storage for future references.

RESULTS

Preliminary clinical studies were carried out at the University of Utah School of Medicine, Salt Lake City, Utah, USA and at the "Dr. Miroslav Zotović" Rehabilitation Institute, Belgrade, Yugoslavia.

Early studies in both normal and SCI subjects have demonstrated interesting findings. Short term studies of normal subjects (10 to 20 minutes of treadmill, at 1 or 2 miles per hour with 0 incline) showed that deliberate variations in gait pattern resulted in recorded sEMG variations of 37% for the quadriceps and up to 90% for the hamstring muscles. When the electrode positions were confirmed using a template and gait pattern was held constant, a maximum of 4% sEMG variation was seen in both hamstring and quadriceps muscles over a series of five treadmill recordings.

Series of long-term studies have provided useful informations about the daily variations of SMA in spinal cord injury patients. A number of technical problems were overcome, such as the touching or soiling of the electrodes, failure of the elastic bandages used to constrain the electrodes and wires, etc.

One sample of a 24 hour recording made on quadriceps muscle of a paraplegic patient is shown in Figure 3.

The value of integration of the signal is that all data is captured and compressed, however, important characteristics of the EMG which might be distinguished such as the difference between a strong short burst of activity and a low level of sustained activity may be reduced to the same value by integration. As most clinically significant sEMG activity does last on the order of one second or longer comparisons of the individual integral periods can be made. This was done for normal subjects and SCI patients, and differences were seen. To ilustrate this, percentile distribution of the integrated sEMG activity samples, for a chosen time interval, is shown, for the SCI patient (Fig. 4) and the normal subject (Fig. 5). Number of occurances of a different sEMG activity levels, between the two graphics cursors (dotted lines on the top traces) are counted. Percentile values are printed in the bar chart form (bottom graphs). The SCI patient recording (Fig. 4) showes significantly less medium activity and more extreme values, both low and high. The recording of normal subject (Fig. 5) showes more gradual changes in the sEMG integral from low to high values. This is seen to correlate with the clinical findings of rapid intense spastic muscle activity in the SCI

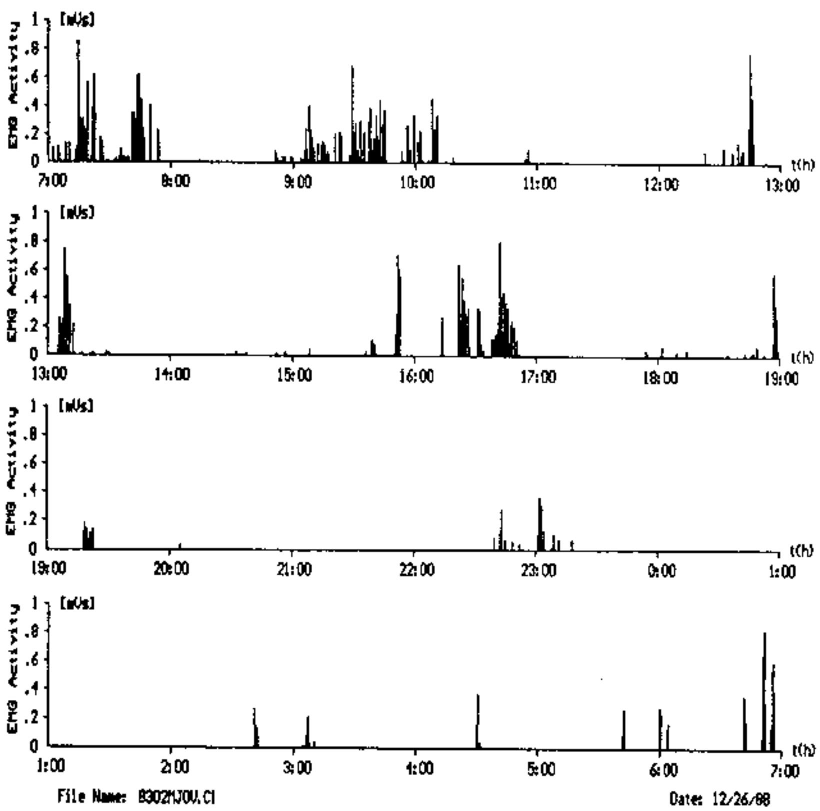

Fig. 3: A sample of 24 hours of recorded SMA (quadriceps muscle) in a SCI paraplegic while performing his daily activities. Patients activities that correspond to recorded SMA were: 6:00-7:00 - wakeing up, bladder emptying, dressing, 7:00-8:00 - tranfer to a wheelchair, morning hygiene, 8:00-9:00 - further dressing, breakfast, 9:00-10:30 - weight lifting, passive exercises, standing in parallel bars, 10:30-12:30 - talking, reading, 12:30-13:30 - undressing, transfer to bed, bladder emptying, dressing, transfer to wheelchair, 13:30-15:30 - lunch, reading, 15:30-17:00 - undressing, transfer to bed, bladder emptying, electrode applying and initiation of the recording (study started at 16:30), dressing, transfer to wheelchair, 17:00-19:00 - supper, TV, 19:00-20:00 - undressing, transfer to bed, bladder emptying, 20:00-22:30 - TV, sleep, 22:30-23:30 - bladder emptying, changing of position, 23:30-2:30 - sleep, 2:30-3:00 - bladder emptying, changing of position, 3:00-6:00 - sleep.

patient as compared to the smooth motion obtained in the voluntary controlled muscles.

DISCUSSION

The time between two dischargings of the integrator (bottom trace on Fig. 2) is 10 ms, which sets the highest possible sampling rate at 100 Hz without any hardware changes. This frequency is chosen to suite long-term studies and could be changed to match any kind of short term studies. In the case of 24 hour studies, the amount of available RAM on the CPU board allows up to 1.5 second increments in time between storing two consecutive samples into memory. This feature requires averaging a

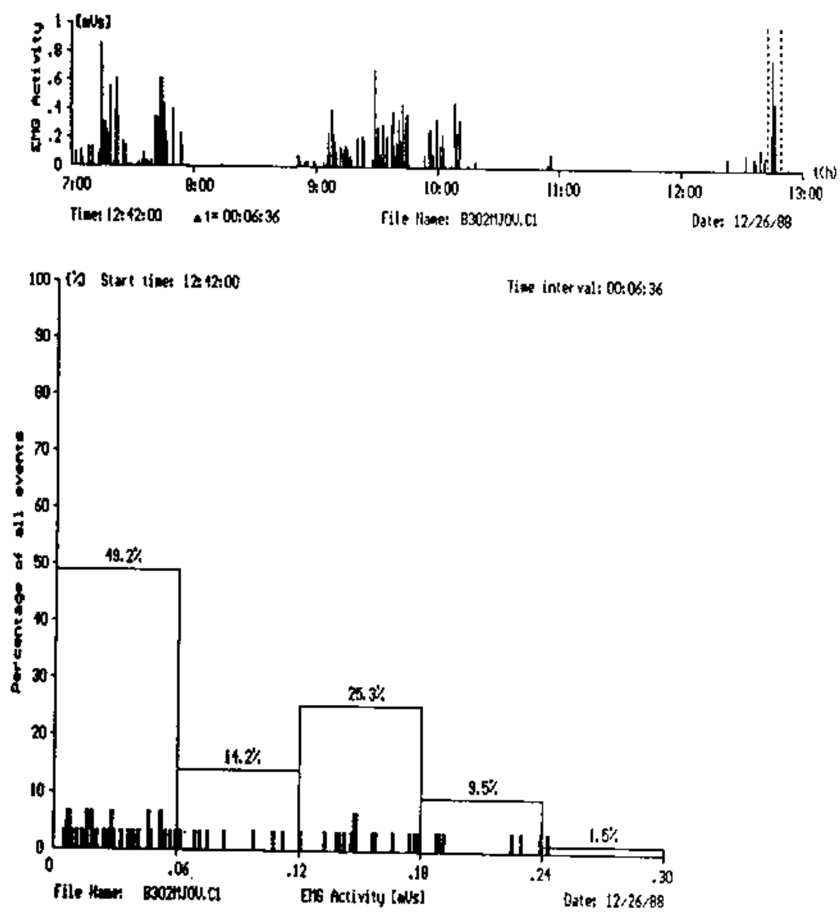

Fig. 4: Percentile distribution of the integrated sEMG activity samples in a chosen time interval, for a SCI patient. Number of occurances, of different sEMG levels, between the two graphics cursors (dotted lines on the top trace), are counted. Percentile values are printed in the bar chart form (bottom graph). Compared to a normal subject data (Fig. 5), there is considerably more extreme activity levels, both low and high.

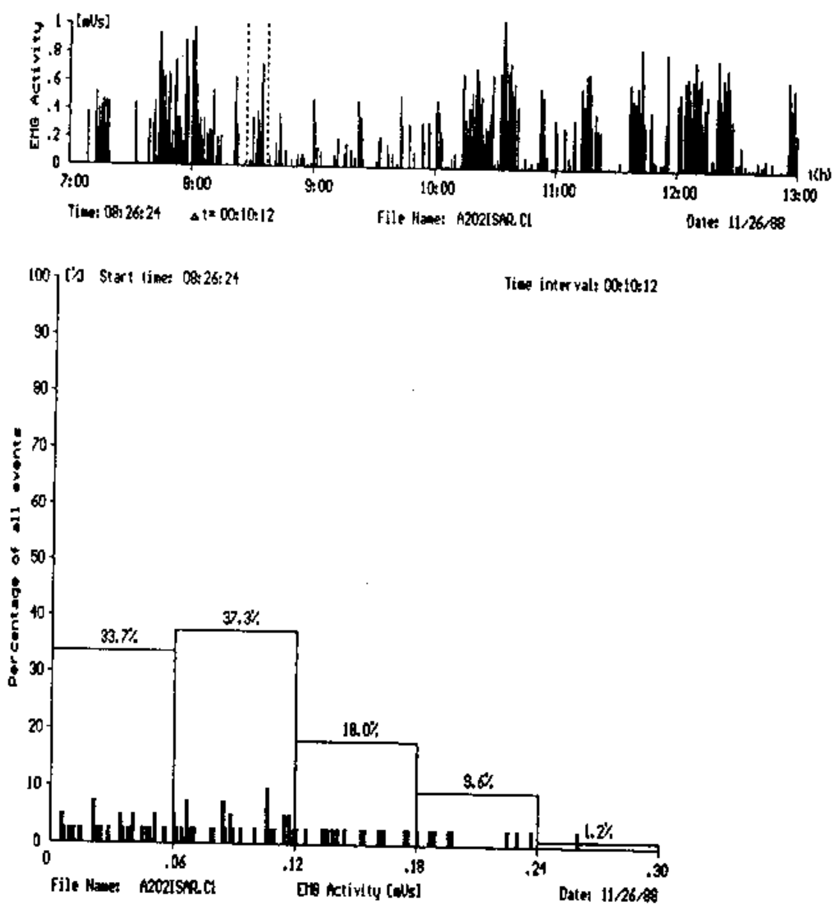

Fig. 5: Percentile distribution of the integrated sEMG activity samples in a chosen time interval, for a normal subject. Number of occurances, of different sEMG levels, between the two graphics cursors (dotted lines on the top trace), are counted. Percentile values are printed in the bar chart form (bottom graph). Compared to a SCI patient data (Fig. 4), there is considerably more medium activity levels.

number of samples before storing the average sample in the memory. The advantage of this approach is that it leaves space for real time data processing between memory storing events. It also brings the flexibility to conduct recordings from 10 min. up to 48 hours in duration. highest resolution possible.

Power consumption is an important aspect in portable devices. Operational power consumption of the device is 125-135mW which means that one alkaline 9V battery can comfortably last for more than 24 hours (30-36 hours within safety limits). Currently 6 AA size NiCd rechargeable batteries are used. They last around 32 hours between rechargings.

Fig. 6: Microcomputer based portable long-term sEMG recording unit: Attachment of the electrodes, sEMG preamplifiers, box containing analog circuitry that performs filtering, rectification and integration of the signal and digital portions of the system and the graphical output on an IBM AT compatible computer. Total weight of the unit is about 700g.

Preliminary studies described hereabove were aimed at evaluating the use of this long-term recording of SMA in spastic SCI patients.

The reliable recording of changes in SMA during a 24 hours period will be useful in measuring and documenting the effect, proper dosage and administration times of various medications and other techniques to control and reduce spasticity.

The analysis of the activity level pattern of muscle may offer a way to distinguish the MA character of normal versus spastic muscle. In other words it would be possible to determine if a residual voluntary control component still exists in sEMG i.e., is the lesion of the spinal cord complete or incomplete.

A promising recent development has been a software feature to zoom in on various chosen areas of the recorded data, which allow the data to be temporally disbursed so that the data representing a standardized event can be analyzed and summed. These standardized events represent the recorded data during (1) a gait cycle for treadmill studies,(2) the upper extremity muscle activity or reflex lower extremity sEMG (depending on electrode placement) while peddling an arm ergometer, or (3) the reflex generated spasticity of the recorded muscle in the CPM device recordings. We feel that comparison of these "event recordings" when recorded over time in the same patients may well by the most reliable and reproducible measurement of spasticity.

Further studies of spasticity distribution necessitates simultaneous recording from a larger number of muscles. Encouraging results with the two channel device prompted the development of an eight channel long-term sEMG recorder which is in prototype stage. This will also allow expansion of these sEMG studies to many other applications.

With a view to further exploring the potential of the method described above for improving the treatment of spasticity in paraplegic patients, it would be interesting to simultaneously examine the same patients by applying our method and one of the existing methods (e.g. pendulum test) for quantitative evaluation of spasticity, focused on another spasticity phenomenon. The advantage of such an approach would be the insight on the moment when short-term study is performed in the light of that day's global SMA.

CONCLUSION

The reliable surface EMG recording system has been developed. It consists of a portable battery operated microcomputer based long-term recording unit and a software package for on/off-line data processing and displaying, running on a PC based host computer. This device, initially developed for recording spontaneous sEMG activity in complete spinal cord injured patients provides useful information about the variation of sEMG over a long period of time (ranging form a few minutes to 24 hours). The information obtained consists of: (1) total integrated surface EMG activity over a chosen period of time (up to 40 hours) with up to 10 ms resolution in time, with the time and event marking and (2) time of day correlation record of motor or other activities. Combination of digital and analog circuitry is made in such a way that it brings the accuraccy and flexibility of the digital system while still capturing all the muscle activity, due to the use of the analog integrator.

The use of the two channel portable sEMG recording device pointed to some interesting new applications in rehabilitation of hemiplegic, quadriplegic and cerebral paralysis patients, as well as for muscle fatigue or functional movement studies.

REFERENCES

1. T. Bajd, and B. Bowman, "Testing and Modeling of Spasticity," J. Biomed. Eng, 4, pp. 90-96, April 1982.

2. T.Bajd and L. Vodovnik, "Pendulum Testing of Spasticity," J. Biomed. Eng., 6, pp. 9-16, January 1984.

3. H.C.Burry, "Quantification of Spasticity: Preliminary Report on a New Method," Annals of Phys. Med., 9, pp. 59-62, May 1967.

4. A. J. Heather and R.A. Graebe, "New Device for the Quantitative Measure of Spasticity," Arch Phys. Med., 46, pp. 332-336, April 1965.

5. H. J. Hermens, J. H. Migchelbrink, W. L. C. Rutten and K. Postema, "Quantification of Spasticity Using Repetitive Movements," Proc. of the 9th International Symposium on ECHE, pp. 375-383, Yugoslav Committee for ETAN, Dubrovnik 1987.

6. W. J. LaJolie and J. W. Gersten, "An Objective Method of Evaluation of Muscle Tightness," Arch. Phys. Med. 33, pp. 595-603, October 1952.

7. W.B. Mattews, "Ratio of Maximum H Reflex to Maximum M Response as a Measure of Spasticity," J. Neurol. Neurosurg. Psychiat., 29, pp. 201-204, June 1966.

8. O. E. Miglietta, and M. Lowenthal, "Application of the Stretch and Hofman Reflexes to the Objective Measurement of Spasticity," Arch. Phys. Med., 42, pp. 258-264, April 1962.

9. O. E. Miglietta and M. Lowenthal, "Measurement of the Stretch Reflex Response as an Approach to the Objective Evaluation of a Spasticity," Arch. Phys. Med., 43, pp. 62-68, February 1962.

10. P.M. Meadows, D. R. McNeal, N.Y. Su and W.W. Tu, "Development of an Implantable and Percutaneous Electrical Stimulation System for Gait Applications in Stroke and Spinal Cord Patients," Proc. of the 9th International Symposium on ECHE, pp. 51-64, Yugoslav Committee for ETAN, Dubrovnik 1987.

11. H.S. Milner-Brown and R.B. Stein, "The Relation Between the Surface Electromyogram and Muscular Force," J. Psycio. 264, pp. 549-569, April 1975.

12. J. P. Roasenda and P.M. Elwood, "A Review of Physiology, Measurement and Management of Spasticity," Arch. Phys. Med., 41, pp. 167-174, March 1961.

13. J. Stenehjem, J. R. Swenson and T. S. Grange, "Spasticity Evaluation by Ambulatory EMG," Proc. of the 9th International Symposium on ECHE, pp. 385-392, Yugoslav Committee for ETAN, Dubrovnik 1987.

Acknowledgements: Work on this project was partly founded by the University of Utah, Department for Physical Medicine and Rehabilitation, Salt Lake City, USA and the Research Council of Srbija, Yugoslavia. The authors are grateful to D. Popović, I. Sarjanović and D. Larsen for their help and useful suggestions.

7. W.B. Mattews, "Ratio of Maximum H Reflex to Maximum M Response as a Measure of Spasticity," J. Neurol. Neurosurg. Psychiat., 29, pp. 201-204, June 1966.

8. O. E. Miglietta, and M. Lowenthal, "Application of the Stretch and Hofman Reflexes to the Objective Measurement of Spasticity," Arch. Phys. Med., 42, pp. 258-264, April 1962.

9. O. E. Miglietta and M. Lowenthal, "Measurement of the Stretch Reflex Response as an Approach to the Objective Evaluation of a Spasticity," Arch. Phys. Med., 43, pp. 62-68, February 1962.

10. P.M. Meadows, D. R. McNeal, N.Y. Su and W.W. Tu, "Development of an Implantable and Percutaneous Electrical Stimulation System for Gait Applications in Stroke and Spinal Cord Patients," Proc. of the 9th International Symposium on ECHE, pp. 51-64, Yugoslav Committee for ETAN, Dubrovnik 1987.

11. H.S. Milner-Brown and R.B. Stein, "The Relation Between the Surface Electromyogram and Muscular Force," J. Psycio. 264, pp. 549-569, April 1975.

12. J. P. Roasenda and P.M. Elwood, "A Review of Physiology, Measurement and Management of Spasticity," Arch. Phys. Med., 41, pp. 167-174, March 1961.

13. J. Stenehjem, J. R. Swenson and T. S. Grange, "Spasticity Evaluation by Ambulatory EMG," Proc. of the 9th International Symposium on ECHE, pp. 385-392, Yugoslav Committee for ETAN, Dubrovnik 1987.

Acknowledgements: Work on this project was partly founded by the University of Utah, Department for Physical Medicine and Rehabilitation, Salt Lake City, USA and the Research Council of Srbija, Yugoslavia. The authors are grateful to D. Popović, I. Sarjanović and D. Larsen for their help and useful suggestions.