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The application of air bag technology: An objective clinical measure of involuntary muscle spasm

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Objectives: To develop a technique which could objectively monitor and quantify spasms in spinal cord injured persons.
Methods: This technique used accelerometers to detect movements in the limb caused by spasms. Accelerometer signals from movements caused by spasms and a variety of movements caused by other subject activities (movement in a wheelchair, transfers etc) were recorded and linear discriminant analysis was used to distinguish between spasms and other activities. Individual spasms were quantified by their duration, magnitude and energy and were recorded over a 24-h period.
Results: Limb movements caused by spasms were shown to be well correlated with the EMG activity of the muscles causing the movement. Movements caused by spasms and movements caused by other subject activities could be reliably distinguished. Subjects showed a characteristic spasm pattern and it was possible to quantify the severity of the spasms and to determine precisely when they occurred.
Conclusion: This technique for monitoring and quantifying spasms has the potential to be used as a clinical tool to aid in the evaluation and prescription of treatment.

Keywords: spasm; spasticity; spinal cord injured

Introduction

Spasticity is a result of an upper motor neuron disorder and is one of the most important impairments of an individual with a damaged central nervous system. A definition of spasticity widely accepted is that of Lance:[1] 'A motor disorder characterised by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the upper motor neuron syndrome.'

Study of patients with spasticity show that the motor difficulties can be divided into positive symptoms and negative symptoms.[3] The negative symptoms include decreased dexterity and loss of strength and the positive symptoms include increased tendon jerks, increased resistance to passive muscle stretch and hyperactive flexion reflexes. Spasticity is used to signify any combination or all these phenomena.

Spasms, involuntary limb movement caused by a manifestation of the positive symptoms, can cause significant disability in patients with spinal cord injury (SCI). These spasms can disrupt sleep, make voluntary activity difficult and, in severe cases, make nursing care difficult if not impossible.[4]

The many different methods for quantifying spasticity indicate the difficulties of clinical assessment. Methods have included: clinical examination,[5,6] tabulation of functional activities,[7] biomechanical and EMG analysis of the resistance of the limb to movement,[8–10] many electrophysiological reflex studies,[1,2,4] EMG responses to perturbation or voluntary movement[10] and gait analysis.

Despite the large variety of tests which aim to quantify spasticity there is no useful uniformly accepted measure.[11,12] Quantification is complicated by other factors such as emotional state, infection and systemic factors and time of day. Many of these tests applied to the same subject at the same time yield conflicting results. In addition these techniques make measurements under laboratory conditions and can only give information on the symptoms at the time when the test is applied. At present the Ashworth scale[5] is the only available clinical measure of tone.

Nearly all SCI individuals will suffer from troublesome spasm at some time and in many cases spasm can seriously disrupt an individual's life. At present there exists no established method for quantifying spasm and therefore there is no way of objectively assessing the extent of handicap and the indication for,

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or the effects of, treatment. Treatment of spasm can be expensive, with significant side effects and can be very time consuming. There is a need to be able to quantify spasms throughout the day and to measure spasms during the person's normal activity. None of the current techniques permit such observations.

With the advent of small piezoresistive accelerometers, principally used in car airbags, and the ability to record this information it is now feasible to be able to monitor limb movements throughout the day. If it is possible to extract, from this information, movements which are due to spasms then a technique could be developed for monitoring spasms during the day. This approach could give a clinically useful profile of the patient's spasm during their normal activities and in addition monitor the effects of treatment.

Table 1 Events were recorded to determine if spasms could be reliably distinguished from other events and accelerometer signals were recorded from a number of different events and from sample periods of spasms. The number of each of these events are given

Event recorded	*Number of repetitions for each event*
Movement in a wheelchair over a flat surface	25
Movement in a wheelchair over a rough surface	24
Movement in a wheelchair through a door	25
Dropping of a small object on the subjects leg	25
Bumping into a wall whilst moving in the wheelchair	25
Transfer from wheelchair to bed and from bed to wheelchair	20
Sample spasms	44

Table 2 Parameters were calculated from the data record of each event (spasm and non-spasm). Each event was separated from the data record. These parameters were then calculated for each event and used to distinguish spasms from non spasms

Parameter	*Parameter definition*
p1	Mean amplitude
p2	Frequency of the maximum peak in the power spectrum
p3	Ratio of the power of the maximum frequency to the total power spectrum
p4	Frequency of the second peak in the power spectrum
p5	Ratio of the power of the second frequency to the total power spectrum
p6–p11	Analysis of p6 and p7 was repeated for the third, fourth and fifth spectral peaks
p12	The difference between the amplitude of the first spectral peak and the second spectral peak
p13	The difference between the amplitude of the first spectal peak and the third spectral peak

Aims

The aim of this study was to develop a technique, using accelerometers, which would permit the monitoring of spasms over a 24-h period. The main objectives of this study were: (1) to demonstrate that movements detected by the accelerometer were spasms caused by rhythmic muscle activity; (2) that movements caused by spasms could be reliably distinguished from movements caused by other movements of the patient (non-spasm events); and (3) to monitor spasm on patients over a number of days and quantify these spasms.

Methods

Nineteen spinal cord injured patients were initially recruited for the whole project (15 males and four females) with varying lesion levels. Ethical approval was obtained from the local ethics committee of the Southern General Hospital in accordance with the Helsinki Declaration of 1975, as revised in 1983.

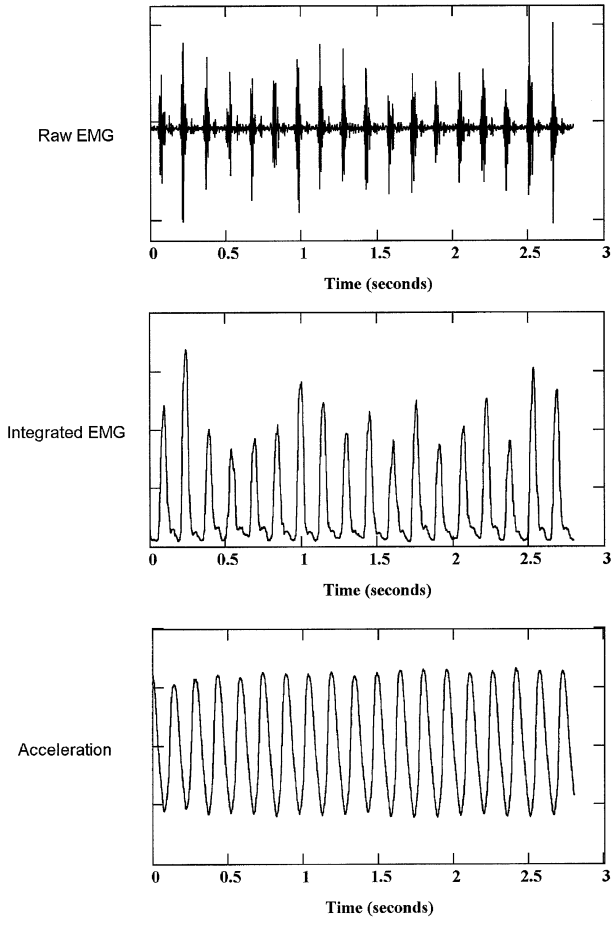

Figure 1 EMG and Accelerometer signals synchronously recorded from the leg of the C5/6 incomplete paraplegic. EMG electrodes were placed over the bulk of the quadriceps. The accelerometer was placed on the anterior aspect of the thigh 2 cm above the patella

EMG and acceleration signals

The accelerometer used to detect limb movement was a piezoresistive accelerometer (Computer Controls Ltd, London, UK; model 3021, range of ± 20 g). This was mounted on a pcb board and then coated in medical grade silicon rubber (total weight of 20 g). EMG electrodes were placed over the quadriceps and the accelerometer was placed over the anterior aspect of the thigh, 2–3 cm above the patella, being secured with Micropore tape. EMG and accelerometer signals were sampled synchronously at 500 Hz on a PC using a 12 bit A/D converter.

Spasms were triggered by the patient or investigator and data were collected. EMG and accelerometer signals were analyzed to determine the relationship between them. This analysis was repeated on seven subjects.

Movement artifacts were observed on most of the EMG recordings and a high pass filter (using a Hamming window) with a cut off frequency of 25 Hz was used to remove these. The signal was then rectified and integrated. The power spectra of both the EMG data and the synchronously recorded accelerometer data were obtained. The cross correlation spectrum, coherence function and signal to noise ratio function between the EMG and accelerometer data were then calculated. All mathematical manipulation of the data was performed using Mathcad (Adept Scientific, Herts, UK).

Distinguishing spasms from other movements

In order to determine if movements caused by other activities could be reliably distinguished from movements caused by spasms, recordings were made of a range of defined activities and also a range of spasms. The set of activities was made up of six events and each event was performed five times by five subjects (Table 1).

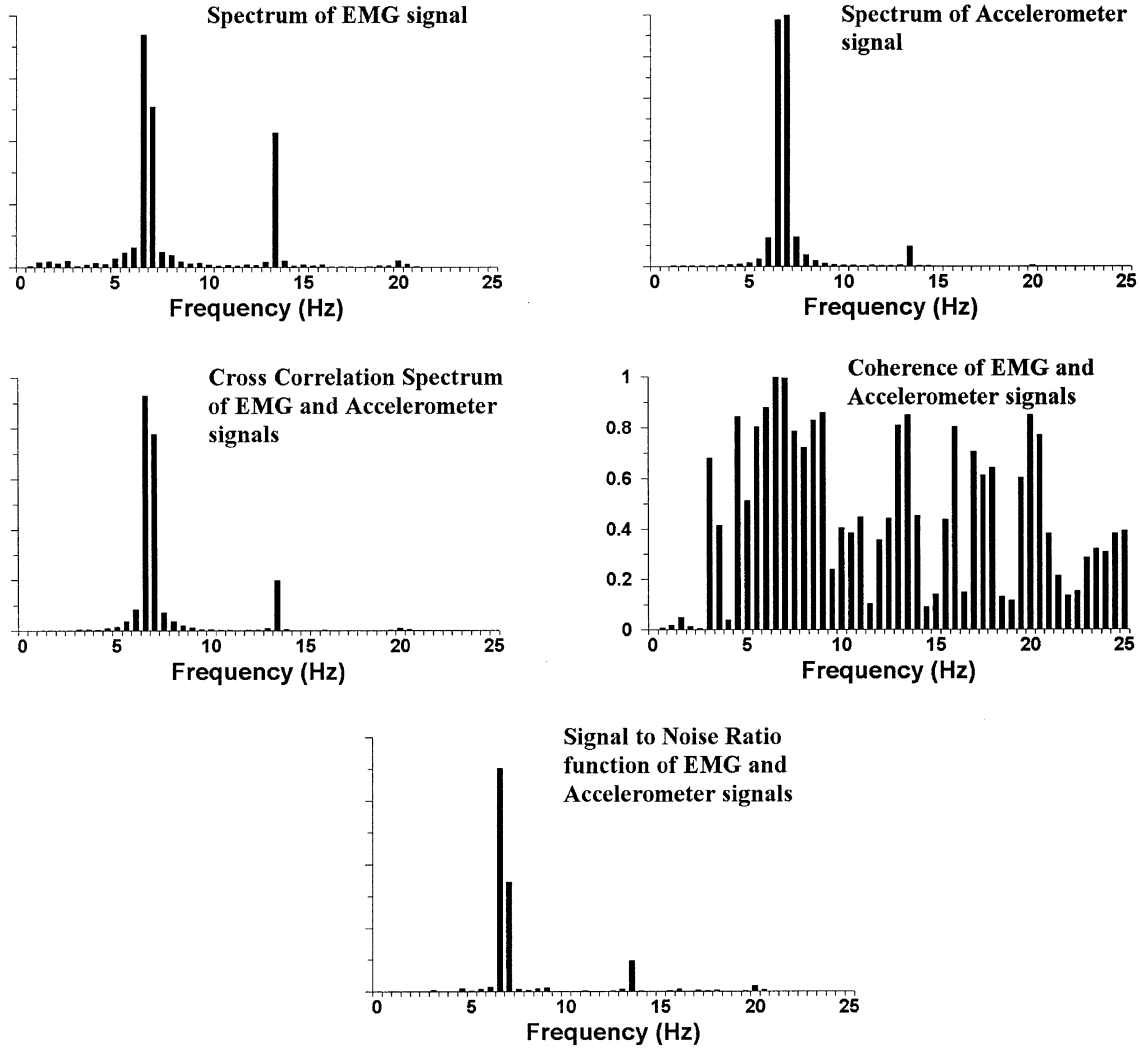

Figure 2 Analysis of EMG and accelerometer signals recorded on the leg of the C5/6 incomplete paraplegic

From the data record each event was delineated manually. Parameters were calculated from the raw data (Table 2). A linear discriminant analysis (SPSS for Windows, version 6.1) was performed using these parameters to classify the data into spasms and non-spasm events. The coefficients of the parameters were obtained using a stepwise procedure. The Wilks' lambda method was used, which minimised the value of Wilks' lambda statistic. For the criteria the default values for F (entry = 3.84 and removal = 2.71) were used.

A total of 188 events were used; 44 spasm and 144 non-spasm events. Different combinations of the parameters were used to determine an optimum number of parameters for appropriate classification.

Twenty-four hour monitoring and quantification

The system for 24-h spasm monitoring consisted of an accelerometer attached to the subject's leg which was connected to a small light-weight data logger (size of 95 mm × 60 mm × 25 mm and weight of 145 g). The data logger (Biomedical Monitoring Ltd, Glasgow) had a memory capacity of 1 MB and included on board data compression software which permitted the continuous recording of 24 h of data. The data logger could be clipped to the subject's clothing, placed behind the wheelchair or placed on the subject's bedside table. Data were recorded at a 50 Hz sampling frequency and subsequently transferred to a PC.

A computer program was then written to automatically process the data and differentiate spasms

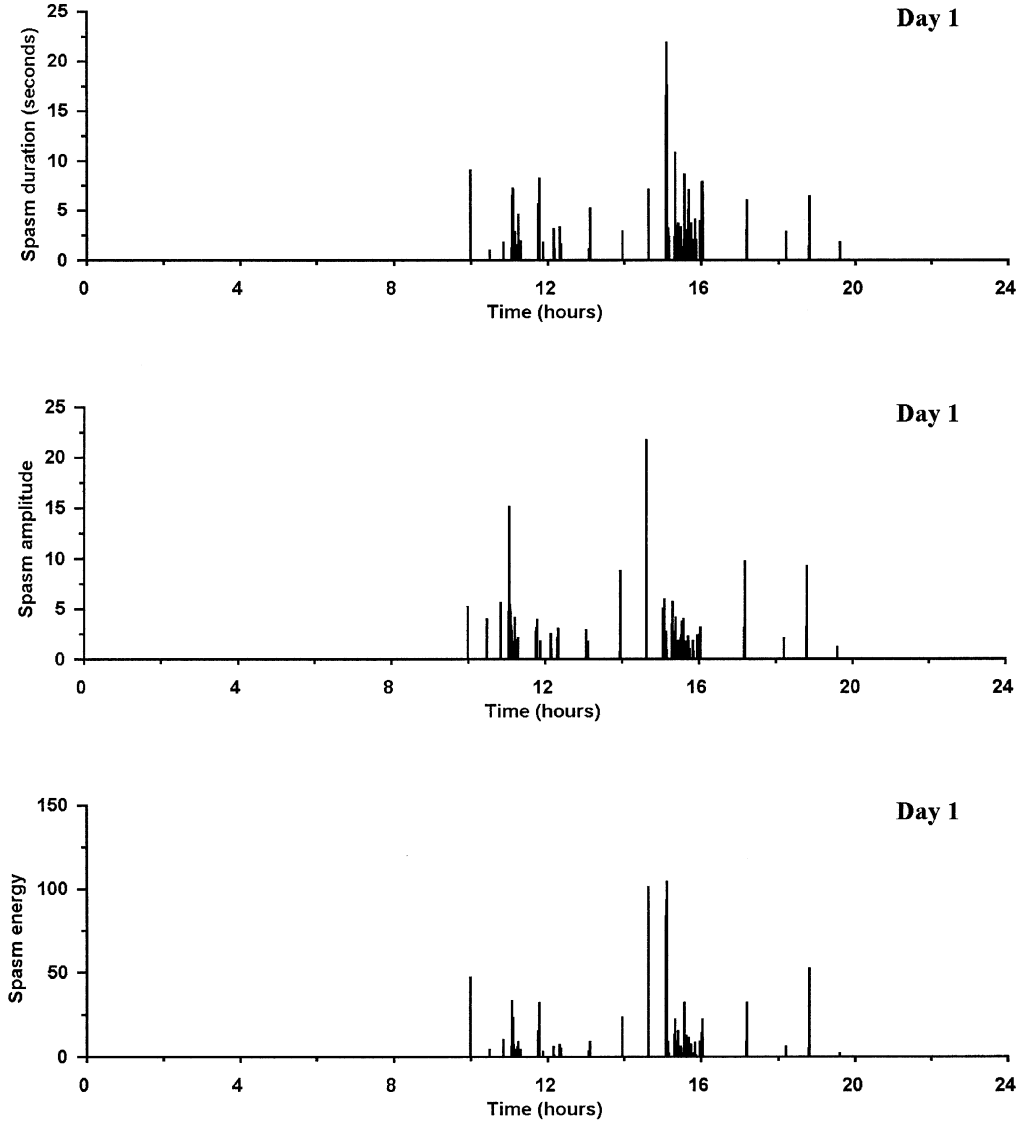

Figure 3 Twenty-four hour record of spasm. The top trace shows the duration of each spasm (in s) over the 24 h period. The middle trace gives the amplitude of each spasm (RMS value of the accelerometer signal) and the bottom trace shows the total energy of each spasm (calculated by multiplying the duration by the amplitude). On this day the subject did not experience any spasm before 9.00 am or after 10.00 pm

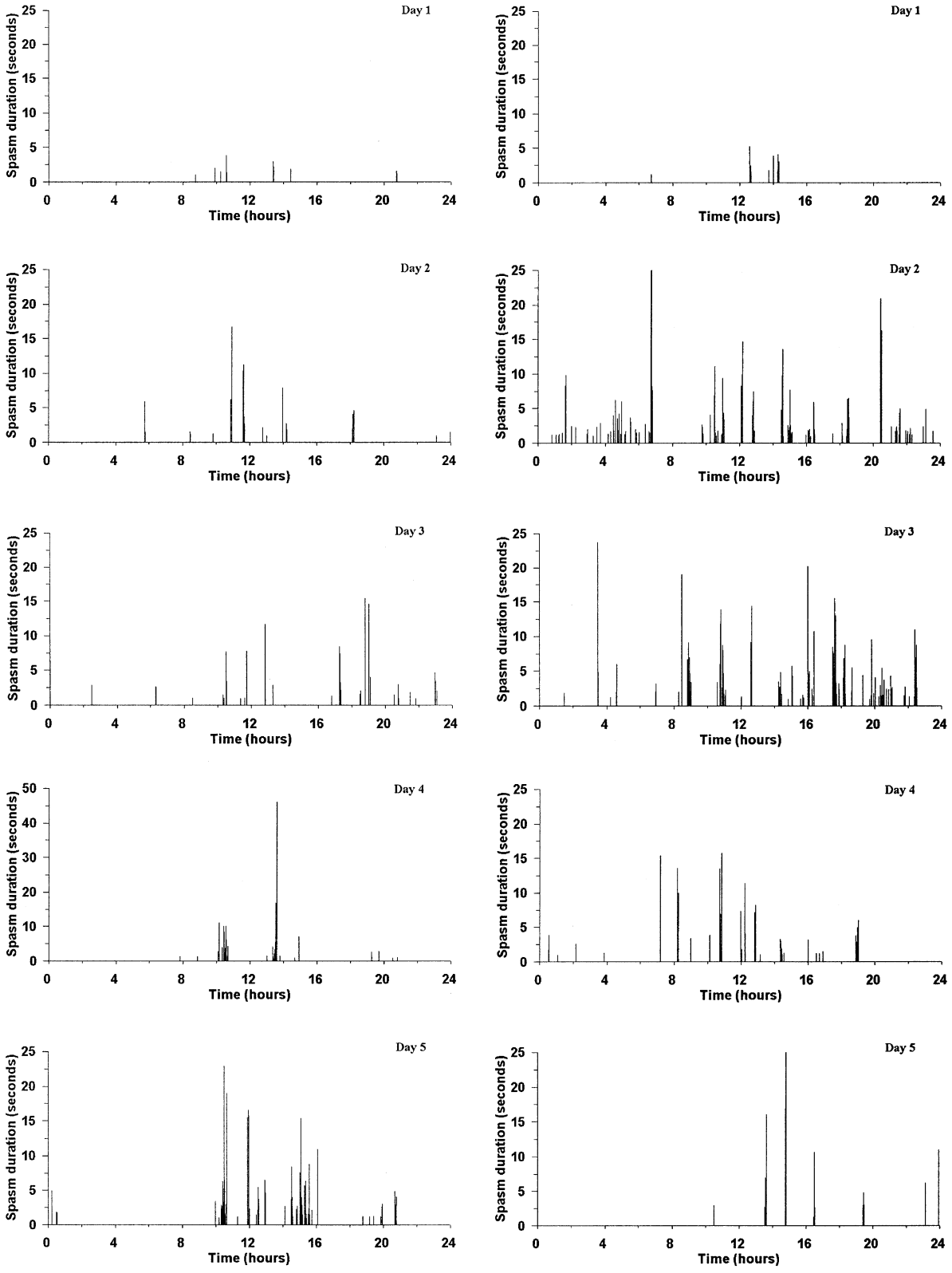

Figure 4 Twenty-four hour records of spasm duration for two subjects on 5 separate days. The left and right column are for different patients. Note that on day 4, for the first patient shown in the left column, the scale is twice that of the other days

from non-spasm events and then calculate parameters to classify the spasm. The ability of the program to do this reliably was tested both with known real data and artificial data.

The algorithm then identified the start and end of the spasm (in real time) and then calculated the following outcome parameters which defined each individual spasm: (i) duration of the spasm (s); (ii) RMS of the amplitude spasm record; and (iii) overall 'energy' of the spasm. This was a product of the previous two outcome measures. Five patients were recruited for this phase. All patients had at least 5 days of 24 h monitoring of their spasms.

Results

EMG and acceleration signals

Figure 1 shows the EMG and acceleration synchronously recorded on one occasion from a C5/6 incomplete spinal cord injured subject.

Data from five spinal cord injured subjects were analyzed and the following results were found from all the recordings (Figure 2): (1) for both the EMG and accelerometer data there was one main peak in the 5–10 Hz region; (2) the coherence function was very close to 1 (all had a value greater than 0.98) for all the recordings for the main peak in the EMG and accelerometer recordings; (3) the signal to noise ratio was maximum at this main frequency component; and (4) there was phase difference between the signals with the EMG leading the acceleration by approximately 70 ms.

Distinguishing spasms from other movements

The main results were: (1) using all the parameters (p1–13) classification was 100% successful; (2) using the main frequency parameters only, the classification was 96.8% successful (one activity was classified as a spasm and five non-spasm events were classified as spasm); (3) using p3 and the difference frequency parameters (p13 and 14) only the classification was 99.5% successful; and (4) using p1 and p6–9 classification was 100% successful. The function used in (4) was then tested on a separate data set. This gave the same classification result.

Twenty-four hour monitoring and quantification

Monitoring of patient spasms was performed successfully on five patients each over five different 24 h periods. Figure 3 shows derived parameters (spasm duration, RMS of spasm amplitude and 'energy of spasm') recorded from one patient over one 24 h period. Figure 4 shows the spasm duration for two patients recorded over five separate 24 h periods.

From the 24 h recordings the main results were: (i) the exact time when spasms occurred could be clearly identified; (ii) different subjects had different daily patterns of spasms; (iii) the number and intensity of spasms within each patient varied greatly from day to day; (iv) many spasms occurred during the day around times of activity such as transfer; (v) there are sometimes uncharacteristic days corresponding to a change in the patient's daily activities (one subject went out drinking the night before and reported that he had a disturbed night (Figure 4; patient 1 day 3)).

Discussion

At present there exists no established method for quantifying spasm and therefore there is no way of objectively assessing the effect of this impairment on the individual or to assess the effects of treatment. Any new method of objectively quantifying spasm with the ability to record these spasms over a 24 h period could be expected to have important consequences for evaluation and prescription of treatments. This study has shown that by monitoring limb movement using an accelerometer and recording this information on a small light-weight data-logger a 24 h record of spasms could be obtained.

It was clear from the analysis of the EMG and acceleration signals that it was possible to use an accelerometer for detecting limb movement caused by spasm. The signal had a large magnitude, clearly distinguishable from other background noise and was well correlated with the muscle activity causing the movement.

From the discriminant analysis it was clear that spasm could be reliably distinguished from the common non-spasm events. It was, however, recognised that the analysis performed here was not exhaustive (in terms of types of events and the number of events) and that using the derived function might result in some events being misclassified.

Using this system it is relatively easy to monitor patient spasms over a 24 h period or longer. This technique offers the following advantages over existing methods: (i) individual spasms can be objectively quantified; (ii) a 24 h record can be made of the patient's involuntary limb movements; (iii) it is possible to identify the precise times of day when the spasms occur and the severity of these spasms in terms of duration, amplitude and 'energy'; (iv) to record the spasms requires a small, light-weight device and which needs a minimal amount of set-up time. Small variations in the placement of the accelerometer would not be expected to be critical but would have a small effect on the calculated parameters of spasm amplitude and spasm energy; and (v) unlike other techniques this does not interfere with the patients' normal activities.

This technique could be routinely used for monitoring spasms and therefore provide clinicians with objective information on the severity and frequency of a patient's spasms. Many treatments used for spasticity are not proven and therefore staff time and health service resources are being used

without any means of audit. This technique could have an impact on the way in which spasms are managed and would allow the more effective targeting and auditing of health service resources.

Conclusion

It is the investigators' opinion that this technique could provide a powerful and important method for quantifying spasm and provide objective and clinically acceptable information on this condition. This technique could be developed further and would benefit from a larger, more detailed, evaluation.

Acknowledgements

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