Increased EMG response following electromyographic biofeedback treatment of rectus femoris muscle after spinal cord injury

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Abstract

Objective To study increases in electromyographic (EMG) response from the right and left rectus femoris muscles of individuals with long-term cervical spinal cord injuries after EMG biofeedback treatment.

Design Repeated measure trials compared EMG responses before and after biofeedback treatment in patients with spinal cord injuries.

Main outcome measures The Neuroeducator was used to analyse and provide feedback of the EMG signal and to measure EMG response.

Setting Department of Traumatic Orthopaedics, School of Medicine, University of São Paulo, Brazil.

Participants Twenty subjects (three men and 17 women), between 21 and 49 years of age, with incomplete spinal cord injury at level C6 or higher (range C2 to C6). Of these subjects, 10 received their spinal cord injuries from motor vehicle accidents, one from a gunshot, five from diving, three from falls and one from spinal disc herniation.

Results Significant differences were found in the EMG response of the right rectus femoris muscle between pre-initial (T1), post-initial (T2) and additional (T3) biofeedback treatment with the subjects in a sitting position [mean (standard deviation) T1: 26 μV (29); T2: 67 μV (50); T3: 77 μV (62)]. The mean differences and 95% confidence intervals for these comparisons were as follows: T1 to T2, −40.7 (−53.1 to −29.4); T2 to T3, −9.6 (−26.1 to 2.3). Similar differences were found for the left leg in a sitting position and for both legs in the sit-to-stand condition.

Conclusions The EMG responses obtained in this study showed that treatment involving EMG biofeedback significantly increased voluntary EMG responses from right and left rectus femoris muscles in individuals with spinal cord injuries.

Keywords: Electromyography; Biofeedback; Spinal cord injury; Lower limb; Rehabilitation; Rectus femoris muscle

Introduction

A spinal cord injury has been defined as a lesion of the spinal cord that results in the disruption of nerve fibre bundles that convey ascending sensory and descending motor information, resulting in temporary or permanent sensory deficit, motor deficit or bladder/bowel dysfunction [1,2]. According to Raineteau and Schwab [1], re-organisation may occur in pre-existing circuits by modifications of synaptic strength (synaptic plasticity), or by new circuits through sprouting or anatomical re-organisation, including growth of axonal branches and dendrites (anatomical plasticity).

Incomplete injuries may have a greater extent of axonal sprouting and axonal growth [3,4]. However, Ramer et al. [5] suggested that if axonal regeneration occurs or if synaptic spaces become occupied with different axons, functional recovery will require retraining to optimise these new circuits.

Significant evidence from both human and animal studies indicates that rehabilitation strategies exploit this plasticity to promote recovery [6]. Rehabilitative therapies may possibly promote a ‘rewiring’ of the cortex to bypass pathways interrupted by an incomplete spinal cord injury, thereby re-establishing supraspinal control of caudal circuitry using novel supraspinal–spinal circuits. In fact, locomotor training on a treadmill after incomplete spinal cord injury in

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humans promotes improved corticospinal drive to muscles of the lower limb that correlates with improved locomotor function [7,8].

Therefore, one approach to activating the nervous system, particularly in the context of the sensorimotor system, is to use rehabilitative strategies that include stimulating somatic sensory afferents and activating functional movements. Thus, the main aims for rehabilitation of an individual with spinal cord injury are compensating for functional loss and using those parts of the sensorimotor system that are still intact [9].

One form of sensorimotor system stimulation in rehabilitation is muscle electrical activity feedback, also known as electromyographic (EMG) biofeedback. This treatment method characteristically uses a device that detects the neuromuscular contractions and provides feedback signals to the subject [10]. This system can provide immediate information about the muscle activation pattern [11]. EMG biofeedback is used to establish learned voluntary control of specific physiological responses, and its effectiveness in this respect has been well demonstrated [12].

The use of EMG biofeedback in the rehabilitation of patients with incomplete spinal cord injuries has already shown significant motor improvement. Brucker and Bulaeva [13] studied the EMG biofeedback treatment responses from the triceps muscles in 75 individuals with cervical spinal cord injuries at level C6 or higher that were greater than 1 year in duration. Estimation of the mean and standard deviation (SD) percentage of normal scores for both the right and left triceps before initial, after initial and after additional biofeedback treatment revealed an average of approximately 13% of normal EMG from the right triceps before initial treatment. This was increased to 33% after initial biofeedback treatment, and further increased to 55% after additional biofeedback treatment. The results were similar in the left triceps.

Therefore, the aim of this study was to investigate whether EMG biofeedback could significantly increase the voluntary EMG response from the rectus femoris muscles of individuals with long-term cervical spinal cord injuries.

Methods

Subjects

The subject group consisted of 20 individuals who were being treated at the Dr. Bernard Brucker Rehabilitation Centre at the Sant’Anna University Centre. The subjects included three men and 17 women. Ten subjects had received their spinal cord injuries from motor vehicle accidents, one from a gunshot, five from diving, three from falls and one from spinal disc herniation.

All subjects had incomplete spinal cord injuries at level C6 or higher. When they were presented for EMG testing and biofeedback, they had already undergone physical interventions (e.g. exercise, electrical stimulation), and had reached a plateau in their functional recovery. The range of level of injury was from C2 to C6. The time since injury was more than 2 years for all subjects (range 2 to 15 years, mean 8.1 years, SD 6.4 years). The mean age of the subjects was 32 years (range 21 to 49 years, SD 8.2 years).

To evaluate suitability for inclusion in the study, the functional neurological classification norms established by the American Spinal Injury Association (ASIA) [14] were used to evaluate the degree of the patients’ sensorimotor involvement after the medullar lesion, along with the Modified Ashworth Scale [15] to determine the degree of spasticity. As a result, patients with ASIA grades A and E and with Modified Ashworth Scale scores of 3 and 4 were excluded. Only individuals with no ankle equinus contracture or other neurological disorders (e.g. brain injury, cognition disorders) took part in this study.

Before examination of physical ability and data acquisition, the subjects were informed of the purposes and procedures to be adopted. Subjects signed a consent form.

Instrumentation

EMG measurements were obtained with disposable surface electrodes Ag/AgCl (Meditrace 200, Kendall Co., MA, USA) connected to a Neuroeducator (Therapeutic Alliances Inc, OH, USA). The Neuroeducator was used to analyse and provide feedback of the EMG signal, measuring EMG by analysing the root mean square voltage with an integral noise level of less than 0.2 μV, a bandwidth of 10 to 1000 Hz, a common mode rejection greater than 140 dB, and a sampling frequency of 1 kHz. EMG signals were integrated over 0.1 seconds, calibrated in μV seconds, and displayed on a colour monitor in the form of a continuous line updated every one-tenth of a second for sweeps of 20-seconds duration.

Procedure

EMG signals were recorded with surface electrodes with a diameter of 20 mm and a centre-to-centre distance of 20 mm. These electrodes were placed over the rectus femoris muscles on both the right and left lower limbs. Electrodes were placed at the midpoint on the line from the anterior iliac spine to the superior part of the patella [16]. A reference electrode was placed on the patella. Prior to fixation of the electrodes, the skin was cleaned with 70% alcohol for the elimination of residual fat, followed by exfoliation using a specific sand paper for skin (Bio-logic Systems Corp., IL, USA) and a second cleaning with alcohol. The electrodes were connected to the Neuroeducator.

The subject was seated in a chair in front of a 19-inch colour monitor. For the pretest (T1), the subjects were instructed to extend their right knee, against gravity, starting with the knee at 90° flexion and the hip held in 90° flexion. The monitor was configured to display the amplitude of the integrated EMG. The T1 data were obtained from the mean of three peak values from the EMG signal recorded from the rectus femoris muscle during knee extension. An identical procedure was used for the left leg. The T1 value obtained
was used to create a criterion line which served as a reference for the start of biofeedback treatment and for comparison with the values obtained after treatment with EMG biofeedback.

After the values of the criterion line were obtained, followed by the initial biofeedback treatment procedure (T2), the subject was warned that the moving line, which he or she was about to see on the monitor, was a reflection of the EMG signal of the rectus femoris muscle.

In the sitting position, the subject was instructed to attempt a knee extension while watching the monitor. Subjects were instructed not to be concerned about the actual extension of the knee. Their task was to increase the magnitude of the moving line to a level higher than the criterion line. The subject was given 20 seconds to complete the task, and was informed every time the amplitude of the EMG signal was higher than the criterion line. After the 20-second training trial was completed, the EMG data were analysed. If the magnitude of the voluntary EMG response was higher than the set criterion, the criterion line was raised to the new larger EMG response.

The procedure was repeated until the magnitude of the EMG response reached a plateau. This required six to eight repetitions. This procedure with its repetitions was first applied to the right rectus femoris muscle and then to the left rectus femoris muscle. After a 10-minute interval, the subject proceeded to the sit-to-stand treatment. The procedure and the criterion line were the same as for treatment in a sitting position. Knee extension in the transition from sitting to orthostatic standing in subjects with ASIA grades C and D was accomplished with the aid of a walker. For some patients with ASIA grade B, additional aid from a therapist was necessary.

Each individual underwent this procedure at 7-day intervals for 4 weeks (four sessions in total). After 3 months without EMG biofeedback treatment, the same biofeedback treatment was repeated for 4 additional weeks. This phase of treatment was named T3. In the interval between T2 and T3, the individuals had no physical treatment.

Data were obtained from the average of the 10 highest peaks in the EMG signal (from a four-session total) recorded from the rectus femoris muscle (right and left) at the end of the EMG biofeedback procedure for T1, T2 and T3.

Statistical analysis

One-way repeated measures analysis of variance was used to compare the mean peak EMG signal for T1, T2 and T3. Post hoc paired t-tests, with a Bonferroni correction to adjust for multiple comparisons, were performed and confidence intervals were calculated to establish whether the observed intervention effects were statistically significant. In this exploratory study, the level of significance of each comparison was set at \( P < 0.05 \). The entire analysis was conducted using StatSoft Inc., OK, USA software.

Results

One-way repeated measures analysis of variance suggested a significant difference in EMG activity between T1, T2 and T3 in sitting and sit-to-stand (Table 1).

For multiple comparisons, paired t-tests were conducted using a Bonferroni method that has acceptable \( P \)-values \(<0.05\), and 95% confidence intervals were calculated for those values. EMG responses in sitting (Fig. 1A) and sit-to-stand (Fig. 1B) for T1 were significantly less compared with T2 and T3 for both the right and left rectus femoris muscles. Significant differences were found in the right and left rectus femoris muscles between T2 and T3.

Discussion

The EMG responses obtained in this study indicate that EMG biofeedback treatment contributed to a significant increase in voluntary EMG response from specific muscles below the level of injury in patients with long-term spinal cord injuries. This finding has important implications for rehabilitation of the spinal cord, and suggests that biofeedback acts on cortical re-organisation, on new neuronal circuits or on spinal cord circuits that have been spared by the lesion.

According to Green et al. [17], functional recovery can occur for several years after an incomplete spinal cord injury, with the degree of recovery dependent upon the re-organisation of circuits that have been spared by the lesion.

![Fig. 1. Mean (standard deviation) of peak electromyographic (EMG) amplitude (μV) of right and left rectus femoris muscles in T1, T2 and T3 in (A) the sitting position (A) and (B) the sit-to-stand position. *Significant difference (\( P < 0.05 \): Student’s t-test).](image-url)
who have reached a plateau in their functional recovery, as spinal cord injuries who have had physical interventions and re-activation of parts of the sensorimotor system that are not normally activated by classical electrical stimulation (and pharmacological agents) can contribute to its practical application, and this error must be corrected in future studies. Moreover, the number of patients was insufficient to study the EMG response in groups of individuals with the same neurological and functional classification proposed by the ASIA [14]. Re-inforcement with physical interventions (e.g. exercise, electrical stimulation) concomitant to biofeedback training, and EMG responses for each neurological and functional classification level (ASIA) are suggested for future studies.

Table 1

Mean peak electromyographic amplitude (μV) for right and left rectus femoris muscles in T1, T2 and T3.

<table>
<thead>
<tr>
<th></th>
<th>T1 mean (SD)</th>
<th>T2 mean (SD)</th>
<th>T3 mean (SD)</th>
<th>Mean difference T1 to T2 (95% CI of difference)</th>
<th>Mean difference T2 to T3 (95% CI of difference)</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Sitting position</td>
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<tr>
<td>Right leg</td>
<td>26 (29)</td>
<td>67 (50)</td>
<td>77 (62)</td>
<td>−40.7 (−53.1 to −29.4)</td>
<td>−9.6 (−26.1 to 2.3)</td>
<td>0.006</td>
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<tr>
<td>Left leg</td>
<td>28 (26)</td>
<td>69 (58)</td>
<td>75 (57)</td>
<td>−42.4 (−58.8 to −31.6)</td>
<td>−4.8 (−16.5 to 6.7)</td>
<td>0.008</td>
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<tr>
<td>Sit-to-stand</td>
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<tr>
<td>Right leg</td>
<td>26 (29)</td>
<td>76 (57)</td>
<td>102 (58)</td>
<td>−60.2 (−78.1 to −46)</td>
<td>−39.8 (−69 to −13.7)</td>
<td>&lt;0.001*</td>
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<tr>
<td>Left leg</td>
<td>28 (26)</td>
<td>94 (58)</td>
<td>130 (80)</td>
<td>−65.6 (−87.5 to −48.9)</td>
<td>−37.6 (−73.3 to −9.9)</td>
<td>&lt;0.001*</td>
</tr>
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</table>

T1, pre-initial treatment; T2, post-initial treatment; T3, additional treatment; SD, standard deviation; CI, confidence interval.

Increased EMG response observed for T3 indicated that the EMG response is progressive even when patients with spinal cord injuries have not had any type of physical intervention for a long period of time. Another important consideration is that the effectiveness of biofeedback techniques for patients with spinal cord injuries is not dependent on the length of time since injury.

Notwithstanding the significant results, this study failed to use the functional evaluation scale (ASIA) after the additional biofeedback treatment in order to observe functional and motor gain of these patients. For this reason, it is not possible to state that the increase in EMG response obtained in this study also reflects functional gains. Consequently, the authors agree that the functional analysis of the patients could contribute to its practical application, and this error must be corrected in future studies.

Furthermore, the number of patients was insufficient to study the EMG response in groups of individuals with the same neurological and functional classification proposed by the ASIA [14].

Re-inforcement with physical interventions (e.g. exercise, electrical stimulation) concomitant to biofeedback training, and EMG responses for each neurological and functional classification level (ASIA) are suggested for future studies.

**Conclusion**

This study indicated that EMG biofeedback contributes to improved voluntary response of the rectus femoris muscle in patients with spinal cord injuries. These results suggest that the effectiveness of the biofeedback techniques in patients with spinal cord injuries is not dependent on the length of time since the injury or initial voluntary EMG response. Moreover, this method of treatment can be used for additional rehabilitation of function in patients who have reached a plateau in their functional recovery and who have not previously had EMG biofeedback treatment. Therefore, additional studies should be performed to establish if the increase in the EMG response really reflects functional gains. Although the answers obtained are important for patients with spinal cord injuries, future studies should investigate whether biofeedback treatment is also of use for the treatment of other muscles of the lower and upper limbs.
Acknowledgement

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Ethical approval: Committee of Ethics in Research of the Medical School of the University of São Paulo, in agreement with the terms of Resolution 196/96, October 1996, the National Council of Health of the Ministry of Health (Protocol Ref. No. 390/2).

Conflict of interest: None declared.

References