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Effects of sustained electrical stimulation on spasticity assessed by the pendulum test

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Abstract: Neuromodulation using electrical stimulation is able to enhance motor control of individuals suffering an upper motor neuron disorder. This work examined the effect of sustained electrical stimulation to modify spasticity in the leg muscles. We applied transcutaneous spinal cord stimulation with a pulse rate of 50 Hz for 30 min. The subjects were assessed before and after the intervention using in a pendulum test setup. The motion of the free swinging leg was acquired through video tracking and goniometer measurements. The quantification was done through the R_{2n} index which shows consistency identifying the spasticity levels. In all incomplete SCI subjects having severe spasticity, the results show that electrical stimulation is effective to modify the increased muscle tone.

Keywords: electrical stimulation; pendulum test; spasticity; traumatic spinal cord injury.

1 Introduction

Traumatic spinal cord injury (SCI) is a striking event that can cause muscle paralysis, neuropathic pain and, in approximately 80% of the affected people, spasticity [1]. Specifically, spasticity accounts for a major reduction in life quality, since it might diminish the ability to perform tasks with the otherwise healthy motor system [2, 3]. Current spasticity treatments often have negative impact on the residual motor control and produce debilitating side effects that decrease the quality of life.

Alternative treatments have been proposed applying electrical stimulation via epidural [4] and transcutaneous electrodes [5, 6]. These studies suggest that an electrical field induced over the spinal cord is able to selectively depolarize the posterior root fibers in the lumbosacral region, leading to the activation of inhibition mechanisms as the Ia inhibitory interneurons and the increase of descending inhibitory activity. This approach has the advantages of not affecting the residual motor control and being reversible [5].

In this work we evaluate the effects of sustained electrical stimulation administrated to the lumbar spinal cord to modify spasticity, and the pendulum test as assessment methodology.

2 Methodology

The preliminary study was conducted in four subjects suffering a clinical incomplete SCI (Table 1). All participants were instructed according the Helsinki Declaration and the study was approved by the Icelandic Ethical Committee. The inclusion criterions were a chronic SCI and a lesion level above vertebra T10.

The spasticity was assessed through the R_{2n} index derived from the pendulum test [7]. The standard pendulum test is done with the subject seated in the edge of a table with the legs hanging freely. Then, the examiner lifts the heel until the leg reaches full extension and waits until no muscle activity is detected; finally, the examiner releases the leg and allows it to swing freely [8, 9]. The index is calculated based on the initial knee angle (α_s), the peak angle of the first swing (α_p) and the final position of the leg (α_f) (eq 1).

The R_{2n} index is adjusted to classify as severely spastic the values near 0 and, non-spastic, the values ≥ 1. This test was selected due to its simplicity and the several

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Table 1: Summary of the demographic data of the subjects, type of injury and classification according to the American Spinal Injury Association Impairment Scale (AIS).

ID	Sex	Age (years)	Years post-injury	Level of SCI	AIS Score
S1	Female	60	3	C8	C
S2	Male	63	45	C7	B
S3	Female	42	25	T6	D
S4	Male	50	3	C4	D

options with which it can be estimated (e.g. goniometers, video tracking, gyroscopes), which make it a suitable option for further multi-center research.

$$R_{2n} = \frac{(\alpha_p - \alpha_s)}{1.6\left(\alpha_f - \alpha_s\right)} \tag{1}$$

For this work, three repetitions of the pendulum test were acquired. Two different measurement techniques were employed to measure knee angle. First, video tracking was used in two volunteers (S1 and S2). This method requires the placement of marker elements (e.g. LEDs) aligned with the hip, knee and ankle joints (Figure 1B). Then, the pendulum test was video recorded from a lateral plane at high speed ($\geq$50 fps). The video was post-processed on the open-source software KINOVEA [10]. On two volunteers (S3 and S4), the knee angle was monitored with goniometers (Biometrics Ltd., UK) digitalized through an acquisition card (NI MyDAQ, National Instruments Inc., USA) at 1.6 kS/s.

Transcutaneous electrical stimulation was applied transversely to the spinal cord (Figure 1A). The active electrode consisted of two self-adhesive electrodes (ø 5 cm, V.Trodes, Mettler Electronics Corp., USA) connected together over the intervertebral space T11–T12. Analogously, the indifferent electrode consisted on two electrodes (7.5 × 13 cm, ValuTrode, Axelgaard Manufacturing Co., Ltd., USA) placed symmetrically over the umbilicus [5]. The stimulation protocol consisted in biphasic current-controlled stimulation continuously applied for 30 min. The stimulation biphasic pulse was symmetrical rectangular, and had a phase duration of 1 ms per phase. The stimulation was applied with a Stimulette R2X (Schuhfried Medizintechnik GmbH, Vienna, Austria) at a rate of 50 Hz.

The stimulation intensity was identified in a pre-test, where defined muscle responses were elicited. In order to apply the appropriate intensity, an amplitude sweep of double pulses (inter-pulse-interval of 30 ms) was performed until a defined muscle response was detected. The applied stimulation intensity for the intervention was chosen as 90% of the smallest activation threshold in all muscle groups.

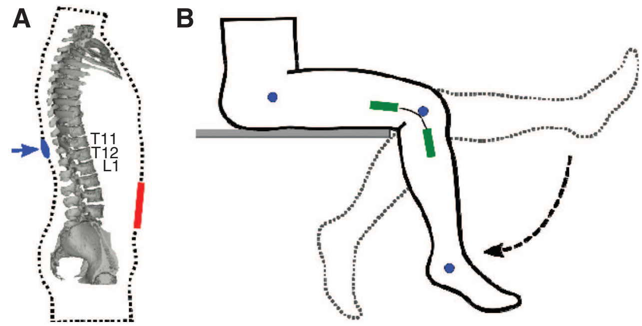

Figure 1: Measurement setup. A) Position of the stimulation electrodes with the cathode (marked with the arrow) placed over the intervertebral space T11–T12 and the anode symmetrically over the umbilicus. B) Movement of the leg during the pendulum test and location of the markers (circles) and goniometer sensor (rectangles).

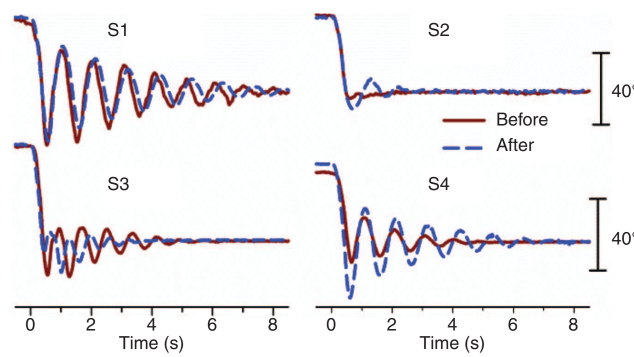

Figure 2: Measurements of the knee angle during the pendulum test before (solid line) and after (dashed line) the stimulation.

3 Results

The clinical protocol was effectively applied on four subjects. Figure 2 shows exemplary results of each subject, before and after the stimulation. Table 2 presents the R_{2n} indexes estimated from the three repetitions before and after the 30-min intervention. The assessment methodology shows a good correspondence between the R_{2n} indexes and the clinical observations, producing consistent values with low standard deviation.

Three subjects had a high muscle tone during the assessment. The results show that the electrical stimulation treatment produced a decrease in spasticity on subjects S2 and S4, which was consistent with clinical observations. S3, on the other hand, presented an increase in muscle tone after the stimulation, which is reflected on the reduction of the peak angle of the first swing (Figure 2). S1 did not present spasticity at the beginning of the assessment and, although a small decrease of the R_{2n} index was detected, the values remain in the non-spastic range.

Table 2: Spasticity indexes before and after the stimulation. The indexes are derived from three repetitions of the pendulum test.

Subject	R_{2n} Index (mean ± SD)	
	Before	After
S1	1.15 ± 0.02	1.05 ± 0.03
S2	0.75 ± 0.06	0.82 ± 0.08
S3	0.90 ± 0.04	0.68 ± 0.06
S4	0.87 ± 0.06	0.93 ± 0.23

4 Conclusion

The pendulum test shows a good consistency on the way to quantify spasticity on incomplete SCI subjects. The R_{2n} indexes were acquired using video tracking or goniometer sensors. In both cases, the index shows its accuracy regardless the acquiring method, which is a valuable characteristic for reproducibility. When the video tracking technique was employed, it was observed that the frames per second should be at least 50, in order to have a stable signal. Additionally, the markers should be preferable active (LED) and the ambient light should be controlled. Otherwise, this method is acceptable to estimate the R_{2n} index, as is cost effective and highly accessible. The goniometers, on the other hand, provide higher resolution and stability after the calibration. The better signal quality could also be employed to estimate other kind of metrics, where smoother signal might be necessary. However, unlike the video tracking approach, the use of goniometers implies a higher cost for the sensors and instrumentation, as well as, longer assembling time.

The use of transcutaneous electrical stimulation, transversely applied over the spinal cord, produce a reduction in spasticity on two out of three subjects that presented it, which is consistent with other works found in literature [5]. The data of S1, which did not present spasticity during the assessment session, shows that the electrical stimulation did not triggered any spasticity. In one case, the spasticity increase after the stimulation, which could follow an altered central state of excitability of the spinal cord.

This preliminary study presents an effective and consistent assessment protocol to evaluate the spasticity levels on subjects with traumatic SCI.

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