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Tapping the Neural Circuitry: Surface Spinal Stimulation in Spinal Cord Injury: A Case Report

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Abstract

Context/Objective: To examine the effect of Surface Spinal Stimulation with varied beat frequency on muscle fibre recruitment in lower limb in Incomplete Spinal Cord Injury. *Design:* Interventional Study. *Setting:* Department of Physiotherapy, Punjabi University Patiala, Punjab, India. *Interventions:* Surface Spinal Stimulation (SSS) was delivered at the T 10 –L1 vertebral level with the adhesive electrodes placed para-vertebrally on each side of spine, 5 cm apart. Rectangular self-adhesive electrodes of size 4.5 cm * 9 cm were used. The electrical stimulations had an amplitude modulated Alternating Current (AC), with a carrier frequency of 2500 Hz, modulated to "beat" frequency of 30 Hz,50 Hz,70 Hz and 90Hz .Stimulation amplitude was raised to elicit sensory stimulation. *Outcome Measure:* Surface Electromyography (EMG) was used to assess the alterations in muscle fibre recruitment of various muscle groups. Pre/Post Test design was adopted. ***Results:*** Pre to Post test SSS values changed significantly with all the varied beat frequencies. *Conclusion:* This case study showed that the SSS, similar to epidural stimulation can be used in enhancing muscle recruitment, without negatively impacting residual motor control in incomplete SCI. Further studies are required to explore more about this non invasive method of tapping the neural circuitry.

Introduction

Background: Detailed characterization of the impact of SCI on CNS motor control processing is a complex and difficult task. Currently, the most widely used method of tracking the recovery of voluntary capability after SCI is the ASIA Impairment Scale *(Waring et al, 2009).* This gold standard has a limitation of not being able to provide the information about the recruitment rate of the target muscle and the activation of synergistic muscles with concurrent inhibition of antagonistic muscles that is necessary to perform functional volitional movement efficiently *(McKay et al, 2011).*

The diminished level of movement that follows a spinal cord injury has been attributed generally to an inability to activate motor pools. There are three salient issues linked to the impaired ability to recruit appropriate bands of motor units in a manner that yields effective movement. First, a significant proportion

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of movement loss is attributable to functional alterations of the spinal circuitry that disrupt the coordination of the motor pools. Second, when a person with incomplete SCI attempts to perform a movement the level of recruitment is insufficient for some motor pools, while actually exceeding normal levels for others. Thirdly, it is well known that chronic SCI leads to a progressive decline in muscle function. All three of these muscle impairments play an important role in recovering functional locomotion *(Verhaagen et al, 2009).*

In the process of major remodelling the aberrant circuits formed after the new synaptic connections may misdirect neural information towards inappropriate motor networks during movement execution. Previous literature pool on electrical stimulation in SCI provides convincing results of the ability in generating effective neural responses (rhythmical, reciprocal activation of the hind limbs in the absence of supraspinal and/or afferent input both in cats and humans) *(Musienko et al, 2012).* This claims the activation of neural circuits in the spinal cord responsible for central pattern generation.

Thus, the coupling of appropriate electrical stimulation and intense training could facilitate stepping and standing in patients with SCI *(Harkema et al, 2011)* and can appropriately tap the spinal neural circuitry. A recent study by the authors also depicts a similar view *(Narkeesh & Bedi, 2015).*

The present case study is an attempt to demonstrate the effect of Surface Spinal Stimulation with varied beat frequency on muscle recruitment in incomplete SCI and thus find an answer to the intricately linked question of activation of intra spinal neural networks that in turn can coordinate and recruit the motor-neuronal pool with enough precision.

Aim of the study: To examine the effect of Surface Spinal Stimulation with varied beat frequency on muscle fibre recruitment in lower limb in Incomplete Spinal Cord Injury.

Materials and Methods:

Design: Interventional Study.

Setting: Department of Physiotherapy, Punjabi University Patiala.

Subjects: 25 year old male with incomplete SCI (T12-L1), ASIA grade C.

Interventions: Pre/Post Test design has been adopted. Surface Spinal Stimulation (SSS) was delivered at the T 10 –L1 vertebral level with the adhesive electrodes placed para-vertebrally on each side of spine, 5 cm apart. Rectangular self-adhesive electrodes of size 4.5 cm*9 cm were used *(Wang et al, 2000).* The electrical stimulations had an amplitude modulated Alternating Current (AC), with a carrier frequency of 2500 Hz, modulated to “beat” frequency of 30 Hz,50 Hz,70 Hz and 90Hz, each time delivered after a gap of 48 hours. Stimulation amplitude was raised to elicit sensory stimulation.

Protocol Outcome Measure: Surface Electromyography (S EMG) was used to assess the alterations in muscle fibre recruitment of various muscle groups. Pre and Post Surface EMG patterns and Root Mean Square for various muscles was considered to obtain the results.

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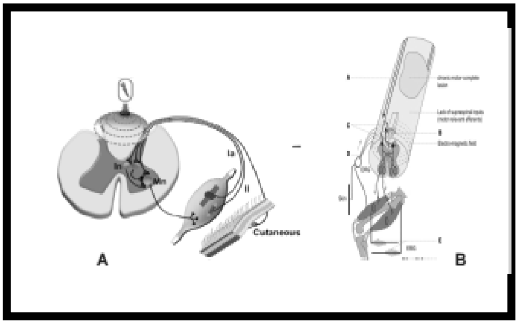
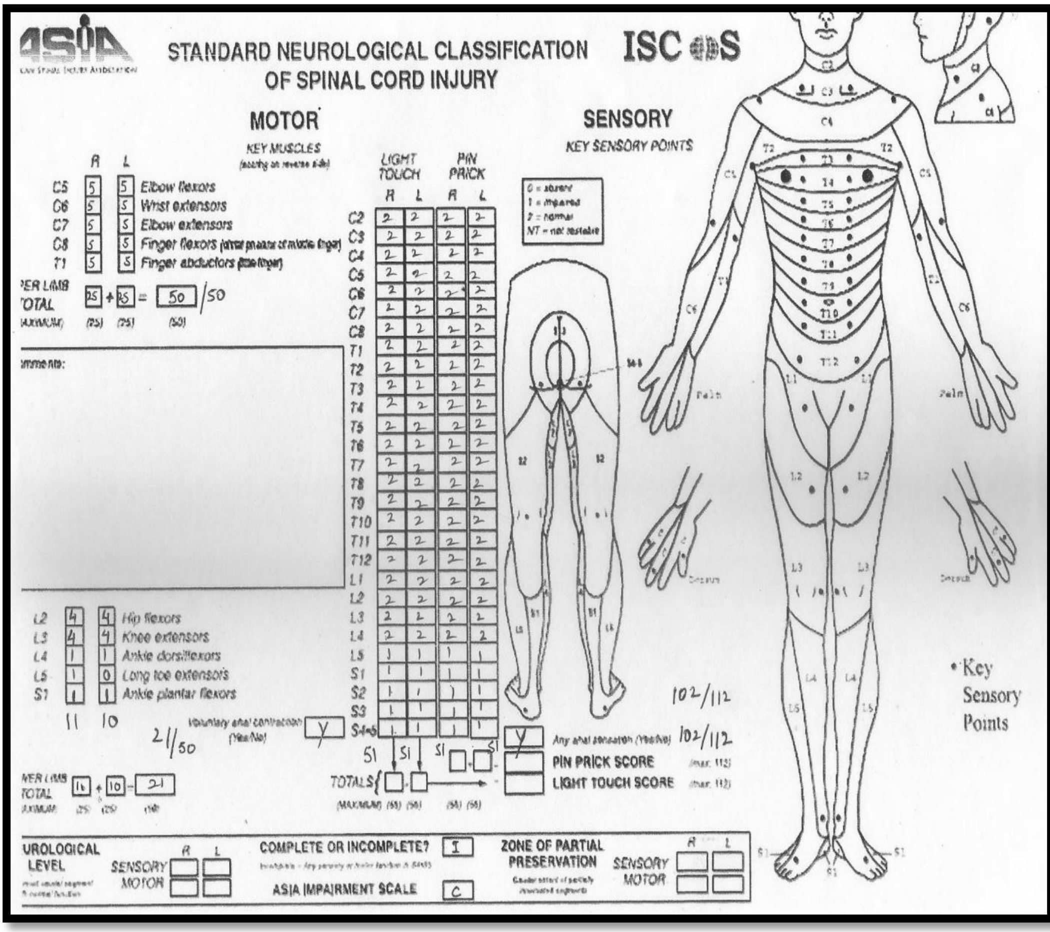


A: Schematic Diagram to show the site and influence of SSS. Surface Spinal Stimulation (SSS) is delivered at the T12-L1 level. B: Schematic diagram to show the activation of intra spinal neural networks that in turn can coordinate and recruit the motor-neuronal pool with enough precision. (Source: Brain.oxfordjournals.org)



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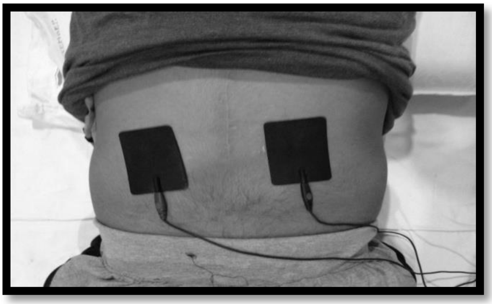
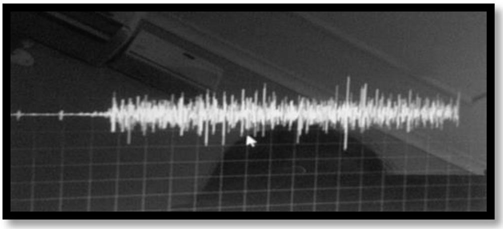


Electrode Placement for Surface Spinal Stimulation at T10-L1 level



Interference pattern obtained from the muscle recruitment through surface EMG

Surface EMG was performed prior to and immediately following the 45-minute session of Surface Spinal Stimulation with varied beat frequency on each alternate day. Electromyographic (EMG) recordings from Quadriceps (Q: RF,VL,VM), Hamstrings (H:BF,SM), Tibialis Anterior (TA), and Tibialis Posterior(TP) muscles bilaterally were acquired using pairs of silver–silver chloride recording electrodes, each placed centrally over the muscle bellies and oriented along the long axis of the muscles with an inter-electrode distance of 3 cm *(Sherwood et al, 1996).* Inter-electrode impedance was reduced to below 5 kΩ using abrasive paste. EMG signals were amplified with a gain of 100, filtered to a bandwidth of 10–500 Hz (Neurostim, Medicad Systems, India). Motor tasks tests included, isometric contraction for Quadriceps (Q: RF,VL,VM), Hamstrings (H:BF,SM) and passive manual movement for dorsiflexors and Plantarflexors Tibialis Anterior (TA), and Tibialis Posterior(TP) muscles bilaterally. Each of the maneuvers was repeated three times on each side, separated by phases of relaxation.

Results

This section displays the Pre and Post Surface EMG patterns and Root Mean Square for various muscles.

Section A describes the tabular details of patterns obtained on S EMG from various muscle groups. With increasing force of contraction, the firing rate of active muscle units increased.

Table 1: Day 1 SSS with 30 hz as beat frequency

MUSCLE	Pre - stimulation RMS voltage		Pre - stimulation RMS voltage	
	Left, mv	Right , mv	Left, mv	Right , mv
Rectus Femoris	80	116	188	133
Vastus Lateralis	140	114	158	236
Vastus Medalis	171	111	188	147
Biceps Femoris	20	25	43	37
Semimembranous	13	12	13	13
Tibialis Anterior	12	12	12	12
Tibialis Posterior	0	0	12	12
	62.29	55.71	87.71	84.29

Table 2: Day 3 SSS with 50 hz as beat frequency

Muscle	Pre stimulation RMS voltage		Post-stimulation RMS voltage	
	Left,mv	Right, mv	Left (mv)	Right (mv)
Rectus Femoris	30	57	188	162
Vastus Lateralis	226	221	222	265
Vastus Medalis	213	195	281	275
Biceps Femoris	34	46	249	241
Semimembranous	0	12	12	12
Tibialis Anterior	12	11	12	13
Tibialis Posterior	11	12	12	12
	75.14	79.14	139.43	140.00

Table 3: Day 5 : SSS with 70 Hz as Beat Frequency

Muscle	Pre - Stimulation RMS Voltage	Post- Stimulation RMS Voltage

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	Left (mv)	Right (mv)	Left (mv)	Right (mv)
Rectus Femoris	**107**	**113**	**192**	**113**
Vastus Lateralis	**203**	**183**	**226**	**241**
Vastus Medalis	**155**	**135**	**199**	**206**
Biceps Femoris	**20**	**43**	**32**	**49**
Semimembranous	**13**	**11**	**33**	**11**
Tibialis Anterior	**10**	**10**	**10**	**10**
Tibialis Posterior	**10**	**10**	**11**	**12**
	74.00	**72.14**	**100.43**	**91.71**

Table 4: Day 7 SSS with 90 Hz as Beat Frequency

Muscle	**Pre - stimulation RMS voltage**		**Post- stimulation RMS voltage**	
	Left (mv)	**Right (mv)**	**Left (mv)**	**Right (mv)**
Rectus Femoris	**30**	**57**	**188**	**162**
Vastus Lateralis	**226**	**221**	**222**	**265**
Vastus Medalis	**213**	**195**	**281**	**275**
Biceps Femoris	**34**	**46**	**249**	**241**
Semimembranous	**0**	**12**	**12**	**12**
Tibialis Anterior	**12**	**11**	**12**	**13**
Tibialis Posterior	**11**	**12**	**12**	**12**
	75.14	**79.14**	**139.43**	**140.00**

The effects of a 45-minute session of SSS with varied beat frequency in a motor-incomplete SCI, ASIA grade C subject have been enlisted in tables above.

The information obtained through S EMG depicts larger volume of muscle activity on delivery of 70 Hz and 90 Hz of beat frequency in comparison to the 30 Hz and 50 Hz of beat frequency. Besides better motor unit activation both in terms of density and intensity in Quadriceps (Q: RF,VL,VM), Hamstrings (H:BF,SM), some juvenile activity was observed in Tibialis Anterior (TA), and Tibialis Posterior (TP) muscles with both 70 Hz and 90 Hz of beat frequency, otherwise not elicitable in the subject. At 90 Hz of beat frequency, muscles of left lower limb performed better than right lower limb. The subject was having grade 1 (ASIA motor score) in ankle dorsiflexors and plantarflexors of both the limbs.

To understand these observations, one must first look to the neuroanatomy stimulated by SSS. It targets deeply located neural structures within the vertebral canal with the aim to provide bilateral multi-segmental input to the spinal cord and subsequently modify the excitability of its circuits *(Minassian et al, 2012).* Within the vertebral canal, large diameter afferent fibers of the L2–S2 posterior rootlets to spinal cord junctions have the lowest thresholds for direct, electrical depolarization (*Minassian et al, 2007).* The ligaments and discs between the vertebral bones reduce the transverse electrical resistance of the thoraco-lumbar spine and allow some current to flow through the vertebral canal *(Ladenbauer et al, 2010; Danner et al, 2011; Minassian et al, 2011).* The excitation thresholds for the posterior root fibers are considerably reduced at their point of entry into the spinal cord due to non-uniformities of the anatomy and its electrical conductivities along the fiber paths and changes of the fiber path direction with respect to the generated field *(Ladenbauer et al, 2010; Danner et al, 2011; Minassian et al, 2011).* Among the fibers within the posterior roots, the Ia afferents have the largest fiber diameters. It is known that the Ia afferents, presumably among the fibers depolarized during SSS, make strong synaptic connections to Ia inhibitory interneurons *(Jankowska, 1992).* This could be the possible mechanism. Independent of the specific mechanisms, the present results suggest that SSS for 45 minutes leads to the improvement of normal physiology (voluntary motor control). If shown to be of wide prevalence, it is possible that this

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therapeutic approach could be used in clinical settings and retrain for voluntary motor control.

Thus, this report serves as evidence that more study designed to characterize the extent and potential mechanisms of SS effect on motor neuron excitability is needed. Taken together, these results suggest that SSS may be able to modify spinal motor responsiveness to external inputs from muscle, tendon, joint and cutaneous receptors while maintaining its responsiveness to input from spinal motor processing generated from within the CNS. *Conclusions:* Surface EMG signal, usually described in terms of the visually analyzed temporal patterns *(Gellhorn, 1947; Hallett, 1983; Waring et al, 2009)* has been used to display quantitatively the patterns of motor unit activity in a variety of motor tasks *(Gellhorn, 1947)*. Its ability to monitor the motor output of multiple muscles has made surface EMG a promising candidate for further SCI characterization. Scientists working with animal models of SCI have been testing a wide array of potential methods to protect spinal cord cells from further damage following injury, to replace subsequently lost cells, and to repair damaged neural circuitry (*Hallett, 1983)*. However, translating these strategies to treat humans with SCI presents significant challenges. Muscle recruitment is controlled by the CNS at spinal level by activated intra-spinal neurons. The authors attempted to determine the effect of a non invasive procedure in tapping the spinal neural circuitry by obtaining its effect on muscle recruitment.The present case study concludes that the presence of appropriate electrical stimulation can tap the neural circuitry and hence can be used to restore functions in SCI.

The present case report is a sub part of a clinical trial: Efficacy Of Activity-Based Therapy In Comparison With Surface Spinal Stimulation In Traumatic Incomplete Spinal Cord Injury With Special Reference To Locomotion- A Central Pattern Generator Controlled Function.

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