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ORIGINAL RESEARCH

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Influence of activity-based therapy and surface spinal stimulation on spinal cord integrity for locomotion and neurological recovery in patients with incomplete spinal cord injury: A case series from India

Parneet Kaur Bedi[1], Narkeesh Arumugam[2]
[1]Doctoral Researcher, Department of Physiotherapy, Punjabi University, Patiala, India
[2]Professor, Department of Physiotherapy, Punjabi University, Patiala, India

ABSTRACT

Objective: To determine the effects of activity-based therapy (ABT) and surface spinal stimulation (SSS) on spinal cord integrity for locomotion and neurological recovery in people with incomplete spinal cord injury (SCI).
Method: Sample of adults (*n* = 5, men, mean age 28.6 years) with motor-incomplete (American Spinal Injury Association Impairment Scale grade C or D) SCI injury. Interventions were conducted as thrice weekly sessions, total of 9 hours per week, consisting of non-invasive SSS and ABT for a period of 24 weeks including developmental sequences; resistance training; repetitive, patterned, rhythmic motor activity, task-specific activities, and locomotor training using body weight support treadmill training. Neurological function (International Standards for Neurological Classification of Spinal Cord Injury), the somatosensory evoked potential for tibial nerve, walking index for spinal cord injury, spinal cord injury functional ambulatory index (SCI-FAI), and spinal cord independence measure-III.
Results: Significant improvements in neurologic function were noted for lower limb motor scores, pin prick, light touch sensations, gait parameter, 2-minute walk test, and the total score of SCI-FAI.
Conclusions: ABT and surface spinal stimulation have the potential to influence the spinal cord integrity in individuals with chronic, motor-incomplete SCI. However, a larger sample size is required to be studied for further understanding and leads to gain insights into meaningful clinical benefits.

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Introduction

Over the past several decades, numerous research studies on animals and humans have demonstrated the capacity of the adaptive plasticity of the spinal cord. Spinal cord exhibits these plastic changes during development and throughout life. This is normally a positive phenomenon, allowing the spinal cord to develop fundamental functions and learn novel behaviors.

Past research studies on animal models have provided significant evidence which indicates that the use of optimal repeated sensory stimulation and intense motor practice, or task-specific exercise and functional training have imperative change on the plastic potential of the nervous schema. Studies have reported that animals who exercise repeatedly and intensely demonstrate changes ranging from increases in growth factors, such as brain-derived neural factor in the central nervous system, that are related to both sensory and motor changes [1,2] with exercise, to arborization of motor neuron dendrites in both intact animals who participate in intense exercise and those with spinal cord injury (SCI) [3]. Others report an increase in axonal sprouting and synapse recovery, as well as motor recovery, after treadmill training in spinal injured rats [4], and reactivation of neural circuits in the spinal cord with forced-use training [5]. Translation of animal findings into human models in experimental studies suggests and supports various interventions that can alter the central state of excitability of human spinal cord and thus induces plastic changes along the neural axis.

Contact Parneet Kaur Bedi ✉ parneet.bedi@yahoo.co.in ☎ 9888229595

Emerging neuro-modulation therapies that complement physical therapy have been proposed to directly stimulate and modify specific impaired neural pathways and thereby produce a more satisfactory functional state. The evidence lines has steered the world of neuro-rehabilitation to interventions which are elementary for patients to achieve functional recovery and recoup into communities. Experimental evidence of improvement in stepping and motor control after activity-based training in animal models and human SCI has been translated into clinical neuro-rehabilitation.

Authors [6] have summarized from previous research studies that there are three fundamental interventions that have been proven successful in altering the physiological state of the spinal circuits and are associated with successful postural and locomotor activity. The first intervention involves the modulation of the locomotor circuits through activity-dependent mechanisms. Several studies have shown that the spinal cord learns to perform the task that it practices. A second intervention involves the modulation of the locomotor circuits pharmacologically. A third intervention is the modulation of the physiological state of the spinal circuitry via spinal stimulation. It seems highly probable that the chronic stimulation techniques presently used to suppress pain and spasticity can be readily adapted to facilitate postural and locomotor control [6,7].

Activity-based interventions or therapies (ABTint/ABT) include any therapy activity, or intervention, that is focused on improving muscle function and sensory perception below the level of injury, and not simply accommodation or compensation for the paralysis and sensory loss due to the SCI, in order to improve overall function after SCI [8]. Spinal cord learns to perform a task which is practiced repeatedly. Repetitive stimuli (sensory/motor/both) can be successfully accomplished as functional outcomes (Image 1-6).

Surface spinal stimulation (SSS) is a non-invasive form of electrical stimulation delivered at the T 10–L1 vertebral level with the adhesive electrodes placed paravertebrally on each side of the spine 5 cm apart. Electrodes are self-adhesive in nature rectangular 4.5 cm * 9 cm in size. The electrical stimulations have an amplitude modulated alternating current, with a carrier frequency of 2,500 Hz, modulated to “beat” frequency of 20–50 Hz and stimulation amplitude is raised to elicit sensory stimulation [9].

This study is a case series set up in a developing country and is an attempt to determine the influence of ABT and SSS on spinal cord integrity

Image 1. Eccentric strengthening of back extensors.

Image 2. Reaching activities in sitting.

Image 3. Strengthening of hip extensors.

Image 4. Strengthening of hip flexors.

Image 5. Sit to stand activity.

Image 6. A subject on BWSTT.

focusing on neurological function, walking ability, and functional independence in individuals with traumatic incomplete SCI.

Materials and Methods

Participation of human subjects was approved by the University Institutional Review Board before the initiation of the study. Patients were explained in detail about the purpose and methods of this research study. Informed written consent was obtained from the subjects.

Participants inclusion criteria: Individuals with incomplete SCI aged 18 years and older, who were at or below the score of 1+ on Modified Ashworth scale, Asia Impairment Scale (AIS) C or AIS D according to International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) grades and willing to attend a 24 weeks protocol on thrice weekly basis.

Exclusion criteria: Patients suffering from any other neurological disorder or pre-existing gait impairment were excluded.

The baseline assessment (day 0) included motor and sensory examination using the International Standards examination in accordance with the ISNCSCI to generate AIS C/AIS D, somatosensory evoked potential (SSEP) for tibial nerve, walking index for spinal cord injury (WISCI-II), spinal cord injury functional ambulatory index (SCI-FAI), and spinal cord injury independence measure Spinal Cord Injury Independence Measure (SCIM-III).

The participants underwent a thrice-weekly session of ABT along with 45 minutes of SSS for 24 weeks. The exercises for the participants were designed according to the principles of ABT. Each session included locomotor training using body weight support treadmill training (BWSTT) for 30 minutes in each ABT session. In this procedure, a portion of the patient's body weight is supported while the patient is assisted to walk on a motorized treadmill with the goal of providing normal kinematic and temporal cues during walking. BWSTT is based on practicing a normal physiologic gait pattern, with attention to the ideal kinematic and temporal aspects of gait.

The sessions were delivered by ABT trained therapist and with the use of equipment/objects available conveniently. ABT included protocol according to its founding principles as found in previous studies [8].

Phase I/II: Reactivation/Reorganization and development/stabilization: Stimulating the nervous system with active assisted exercises and use developmental sequencing to develop joint stabilization.

Phase III: Strength: Initiate eccentric and concentric muscle contractions through positional movement or stimulation.

Phase IV: Function and coordination: Improve coordinated movement through all planes of movement and motion. Most exercises are performed in load-bearing position. Mainly free standing.

Phase V: Gait training: Focus on proper gait mechanics and the ability to move over the ground in multiple planes of motion.

ABT with its origin and popularity in the western world utilizes state of art equipment for inducing changes in spinal excitability. It is a highly specific intervention which focuses on functions below the level of injury. ABT purely discourages compensatory mechanisms and focuses on developing appropriate plastic changes in spinal circuitry. Spinal neuronal circuits below the level of the lesion can be activated by an appropriate afferent input, leading to training effects. In developing countries like India, where affordable healthcare and rehabilitation is a prime area of concern, the development and implementation of a unique and cost-effective rehabilitation program for SCI is quite encouraging.

Clinical and electrophysiological data

Lower-limb voluntary muscle strength was measured by a trained examiner using the American Spinal Injury Association lower extremity motor score. Spinal cord integrity was assessed via electrophysiological recordings according to SSEPs elicited from the tibialis posterior nerve. SSEPs were elicited dorsal of the malleolus medialis, and the recording electrodes were placed in the Cz′-Fz configuration according to the international 10/20 system. SSEPs were evaluated by taking into account both response latency and amplitude, as reported previously for SSEPs (21), resulting in a five-point impairment scale.

Functional improvements

WISCI-II, SCI-FAI, and SCIM-III were used to determine the improvements in functional capacity and locomotion. Higher score depicted better outcome.

Statistical Analysis

Analysis was performed using SPSS 20 software. Repeated measures ANOVA has been used with p value < 0.05 and significant at 95% confidence interval. The following table describes the mean values and mean difference for the parameters at baseline, 12 weeks, and 24 weeks. The authors have found statistically significant changes in lower limb motor scores (LEMS), pin prick (PP), light touch (LT) sensations, gait parameter, 2-minute walk test (2-minWT), and total score of SCI-FAI. However, statistically non-significant changes were found in scores of WISCI-II, SCIM, t SSEP, temporal, and assistive device parameters of SCI-FAI.

Results and Discussion

The present work is discrete in its implementation of ABT intervention in cost effective manner along with non-invasive spinal stimulation for patients with incomplete SCI, for a period of 12 months and determining the influence on spinal cord integrity focusing on neurological function, walking ability, and functional independence.

Though, no change was observed in the score of assistive devices, temporal parameters of SCI-FAI, t SSEP, SCIM, and similarly WISCI-II scoring. It was observed that there was a statistically significant change in lower extremity muscle strength, PP and LT sensation, gait parameter, total score of SCI-FAI, and 2-min WT of SCI-FAI. These results have been found to be analogous to a number of other studies that have reported improvements in lower limb strength and gait for participants with both chronic [10–12] and sub-acute SCI [13].

The theoretical underpinning for developing specific training for individuals with SCI comes from research works which studied the recovery of locomotion in cats with SCI [14]. A viable neuro-physiological description for these motor responses may be that the afferent signaling,

Table 1. Mean difference value at baseline, 12 weeks, and 24 weeks for various outcome measures.

Variable		Mean	SD	*F*-value (0 *vs.* 3 *vs.* 6) months	*p*-value
WISCI	Baseline	13.4	4.33	1	($p < 0.05$) Ns
	PI-I	13.6	4.66		
	PI-II	13.6	4.66		
	Mean diff.	0.2	4.24		
LEMS	Baseline	18.6	7.09	35.23	$p \leq 0.05$
	PI-I	23	5.09		
	PI-II	24.4	5.54		
	Mean diff.	5.8	6.73		
PP	Baseline	100.6	2.60	14.70	$p \leq 0.05$
	PI-I	102	3.46		
	PI-II	103.6	3.84		
	Mean diff.	3.0	3.47		
LT	Baseline	100.6	2.60	14.70	$p \leq 0.05$
	PI-I	102	3.46		
	PI-II	103.6	3.84		
	Mean diff.	3.0	3.47		
SCIM	Baseline	86.6	9.20	2.78	$p \geq 0.05$
	PI-I	88.8	8.89		
	PI-II	89.8	7.91		
	Mean diff.	3.2	8.27		
t SSEP	Baseline	2.2	0.44	0.44	$p \geq 0.05$
	PI-I	2.4	0.54		
	PI-II	2.2	0.83		
	Mean diff.	0.0	0.63		
Gait	Baseline	12.2	3.83	12.49	$p \leq 0.05$
	PI-I	15.4	2.19		
	PI-II	17.2	2.28		
	Mean diff.	5.0	3.97		
Assistive devices	Baseline	9.8	2.77	2.25	$p \geq 0.05$
	PI-I	10.4	2.50		
	PI-II	10.4	2.50		
	Mean diff.	0.6	2.51		
Temporal parameter	Baseline	4.2	0.83	3.50	$p \geq 0.05$
	PI-I	4.6	0.54		
	PI-II	4.8	0.44		
	Mean diff.	0.6	0.70		
SCI-FAI total score	Baseline	26.2	6.4	25.55	$p \leq 0.05$
	PI-I	30.6	4.4		
	PI-II	32.6	4.87		
	Mean diff.	6.4	6.36		
2-minute WT	Baseline	124.8	38.97	7.42	$p \leq 0.05$
	PI-I	148.8	62.91		
	PI-II	164.4	60.68		
	Mean diff.	39.6	52.41		

continuous movement, and the repetition of each movement could stimulate neural circuits of locomotion control, which makes up the so-called central pattern generator at the spinal level [15,16]. Training stimulates neuronal activity and it produces a better activation of the spinal centers of locomotion control. ABT and SSS in patients with incomplete SCI can be an important and cost-effective ally in motor rehabilitation. Both these interventions target neural plasticity [16]. This learning depends on specific sensory inputs associated with the fulfillment of a motor task and the repetitive practice of this task [16]. These interventions have the ability to alter the central state of excitability of the spinal cord but a randomized trial on the larger sample can provide stronger evidence.

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