

Effects of Body Weight-Support Treadmill Training in Incomplete Spinal Cord Injury: A Critical Review

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Abstract: Problem statement: The present study reviewed the efficacy of body-weight support treadmill training in patients with incomplete spinal cord injury. **Approach:** We developed a computer-supported search strategy for finding studies in the main data bases: Pubmed/Medline, ISI Web of Knowledge and Scielo. We also developed a manual search withing all electronically references found. The search terms gait, locomotor training, spinal cord injury, SCI, body-weight support treadmill training were used. Only papers published in English and conducted from 1991 up to 2012 were preferentially reviewed. The inclusion criteria were: (a) studies using body-weight support treadmill training in patients with iSCI; (b) studies with iSCI patients classified as ASIA C or D. The exclusion criteria were: (a) studies comparing the BWSTT with manual and robotic techniques and associated BWSTT with the use of drugs. **Results:** After a careful electronic search in the data bases, forty seven articles were found. Studies with patients of ASIA A and/or B²⁶ classification, studies comparing the BWSTT with manual and robotic techniques and studies associating BWSTT with the use of drugs were excluded of the study. Thus, only 21 articles were selected. **Conclusion:** iSCI is a severe neurological condition that causes serious compromises, such as gait disability. The wide use of BWSTT seems to be an effective, safe and reliable method for functional rehabilitation of gait. Even though, there is no sufficient scientific evidence to confirm that the BWSTT is superior to the other rehabilitation techniques.

Key words: Spinal Cord Injury (SCI), range of motion, Body Weight Support Treadmill Training (BWSTT), rehabilitation techniques

INTRODUCTION

Approximately 259,000 people with a Spinal Cord Injury (SCI) live in the United States. SCI is classified according two criteria: the neurological level and if the injury is complete or incomplete. Of those SCI patients, approximately 30.1% have incomplete tetraplegia. This level of lesion is classified "D" on the American Spinal Injury Association Impairment Scale (AIS), due to the preservation of some sensorimotor functions below the level of injury, often at the level of cervical backbone (NSCISC, 2009).

The ability of muscle to function against gravity is preserved in more than half of all muscle groups below the neurological level of injury. However gait patterns in this population often reflect incoordination of muscle action, leading to inefficient gait, with high-level

energy consumption (Cunha-Filho *et al.*, 2003). Although able to ambulate, these people are often unable to isolate specific muscle patterns to ambulate at functional speeds and without significant gait deviations. Gait impairments in people with incomplete SCI (iSCI) are not only induced by alterations in motor control, but also by muscle weakness, decreased range of motion and decreased muscle extensibility (Gracies, 2005; Biering-Sorensen *et al.*, 2009), improving quality of life through functional independence, improving self esteem and social inclusion of these patients.

In addition to its severity and irreversibility, the iSCI requires long and costly rehabilitation programs that in general lead to functional recovery. In front of the difficulties of the traditional gait training, Body Weight Support Treadmill Training (BWSTT) was created (Cunha *et al.*, 2002). It allows for the repetitive

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practice of walking/stepping in a controlled environment, which the patient's weight is partially unloaded and sensory input is provided that facilitates normal walking parameters (Cunha *et al.*, 2002; Visintin *et al.*, 1998; Wilson *et al.*, 2001; Field-Fote, 2000) Research has shown improvements in functional walking ability in both acute and chronic ISCI populations after locomotor training with BWSTT (Hicks *et al.*, 2005; Wernig *et al.*, 1998; Wirz *et al.*, 2005).

The theoretical basis for the emergence of BWSTT results from studies in cats with spinal cord injuries that have passed through gait training (Threlkeld *et al.*, 2003). From these studies it was found a central pattern generator that was responsible for generating the cyclical pattern of movement in the central nervous system of these animals, even with little training after SCI (Duysens and Crommert, 1998; Schindl *et al.*, 2000; Miyai *et al.*, 2000). Historically, BWSTT is linked to neurological impairment, which was firstly used in stroke patients (Hesse *et al.*, 1999; Barbeau and Visintin, 2003) and SCI (Visintin and Barbeau, 1989; Gardner *et al.*, 1998), but now it has been used to treat various neurological and orthopedic diseases. Thus, this study aims to investigate the efficacy of BWSTT in iSCI rehabilitation.

MATERIALS AND METHODS

The present paper reviewed the efficacy of body-weight support treadmill training in patients with iSCI. We developed a computer-supported search strategy for finding studies in the main data bases: Pubmed/Medline, ISI Web of Knowledge and Scielo. We also developed a manual search withing all electronically references found. The search terms gait, locomotor training, spinal cord injury, SCI, body-weight support treadmill training were used. Only papers published in English and conducted from 1991 up to 2009 were preferentially reviewed. The inclusion criteria were: (a) studies using BWSTT in patients with iSCI; (b) studies with iSCI patients classified as ASIA C or D; (c) studies using BWSTT in combination with electrical stimulation in patients with iSCI. The exclusion criteria were: (a) studies comparing the BWSTT with manual and robotic techniques and associating BWSTT with the use of drugs.

RESULTS

After a careful electronic search in the data bases, forty seven articles were found. Studies with patients of ASIA A and/or B (Maynard *et al.*, 1997) classification, studies comparing the BWSTT with manual and robotic techniques and studies associating BWSTT with the use of drugs were excluded of the study. Thus, 14 studies

were selected and the main were summarized in Table 1 with their respective methods and outcomes.

DISCUSSION

Fourteen of the twenty-one articles found (Gardner *et al.*, 1998; Field-Fote and Tepavac, 2002; Wernig and Müller, 1992; Wernig *et al.*, 1995; 1998; Nymark *et al.*, 1998; Behrman and Harkema, 2000; Protas *et al.*, 2001; Field-Fote, 2001; Postans *et al.*, 2004; Field-Fote *et al.*, 2005; Lucareli *et al.*, 2008; Behrman *et al.*, 2008) showed that treatment with BWSTT in iSCI (ASIA C and D) have positive effects on spatial and temporal parameters of gait, such as symmetry, O₂ consumption (lower energy expenditure), coordination, swinging arms, motor function, stride length, distance and walking speed. The remaining of studies showed other effects of BWSTT beyond gait characteristics. Improved blood glucose regulation (Phillips *et al.*, 2004), little or any improvement in quality of life (Lucareli *et al.*, 2008; Effing *et al.*, 2006), changes in electromyographic activity in the main muscles of gait (Gorassini *et al.*, 2009) and increase in muscle fiber were also observed after BWSTT.

Three out 21 studies (Wernig *et al.*, 1995; 1998; Field-Fote *et al.*, 2005) were randomized clinical trials and/or experimental studies of more than 20 patients. The rest were case reports, case-control pilot study and /or experimental studies of less than 20 patients. Despite the positive outcomes found in favor of BWSTT, reliable scientific evidence is needed in order to confirm these findings.

BWSTT provides specific activation of the neuromuscular system below the level of injury in order to "retraining" the CNS and restore motor skills. Researchers examined the role of the spinal cord to control the walk and found that cats with complete transection of thoracic spinal cord could restore locomotion, after intense practice of walking exercises, in order to improving normal gait parameters, such as, walking speed and appropriate kinematic (Behrman and Harkema, 2007).

Within this context, BWSTT is tough to be superior compared to conventional gait training in neurological disorders, such as stroke (Cunha *et al.*, 2002; Daly *et al.*, 2004; Visintin and Barbeau, 1998), Cerebral Palsy (CP) (Schindl *et al.*, 2000) and Parkinson's Disease (PD) (Miyai *et al.*, 2000). In stroke patients, a randomized clinical trial was conducted comparing the conventional physical therapy intervention (4 daily sessions, 3 h each) with BWSTT (4 daily sessions, 20 min. each) in 15 stroke patients in acute phase (< 6 weeks). Investigators verified the functional gait, the speed obtained in 5 meters, the distance traveled in 5 min and the energy expenditure (oxygen consumption -VO₂max.).

Table 1: Summary of BWSTT studies in SCI rehabilitation

Authors	N	Protocol	Outcomes
Wernig and Müller (1992)	8 iSCI (male) (5-20 years after injury)	The time of treatment was 1½ to 7 months, therapy session ranged from 30-60 min. The use of BWSTT started with 40%.	The distance increased after training. The important phenomenon observed was that patients with absent voluntary activity in the limb at rest, was able to ambulate 100-200 meters (locomotor automatism).
Wernig <i>et al.</i> (1995)	89 iSCI (male) 44 in chronic phase and 45 (in acute phase) 64 controls	The treatment with BWSTT had an average of 10.5 weeks (3-20 weeks), and patients who ambulate, improved therapy session 30 min. (5 times/week).	Patients acquired independent gait, speed and performance of the gait. Although there has been little improvement in voluntary muscle activity.
Gardner <i>et al.</i> (1998)	1 iSCI (male)	Patient injured between C5-C6. Training in the BWSTT with 40% weight bearing, for 6 weeks (3 times/week) 16 sessions (20 min each).	Improved performance in the race and in the cadence of the gait.
Wernig <i>et al.</i> (1998)	76 iSCI (male) (35 in chronic phase and 41 in acute phase)	Patients trained in the BWSTT an average of 12 weeks (sessions with 30 min.(5 times/week) and patients in acute phase, trained in BWSTT, an average of 10 weeks (sessions with 30 min, 5 times/week).	Improved function of moving from wheelchair to walking. Ambulation patients, improved gait speed and endurance and keep the winnings for an extended period after training.
Nymark <i>et al.</i> (1998)	5 iSCI (male) (sub acute phase, 2 months after injury)	Patients injury among C2-T10. All participants trained in the BWSTT for 36 sessions (1 h each) along 3 months.	Improved range of motion and kinematic measures temporal and spatial) of the gait. (More weight bearing in lower limbs.
Behrman and Harkema (2000)	3 iSCI (male)	Patients ASIA C and D training in the BWSTT. Case 1- Men, 20 years, injury in T5, ASIA C, one month after the event, with key muscles motor score 2/50 in lower limbs. Case 2- Men 43 years, injury in C6, 8 months after trauma, ASIA D, key muscles score 32/50. Case 3- Men, 45 years, injury in T-9, ASIA D, lower limbs key muscles score 46/50.	Case 1- Improved walking speed and independence at home, just starting to use a cane for mobility. After the whole training, progressed to Asia D and Key muscles improved to 38/50. Case 2- After training, remained ASIA D, key muscles score improved to 34/50. After complete training became full time ambulant with crutches. Improvement in walking speed, balance, fall risk and quality of life. Case 3- He did not have any change in classification and motor score of ASIA, improved in climbing stairs and walking speed.
Protas <i>et al.</i> (2001)	3 iSCI (male)	Patients iSCI injured in thoracic level, 2 cases ASIA D and 1 case ASIA C. Training in the BWSTT with 40 % weight bearing, sessions of 20 min, 5 times/ week during 3 months.	All three patients improved in walking speed and efficiency, reduced O ₂ consumption in 68%. The muscle function did not change.
Field-Fote (2001)	19 iSCI (male)	(<1 year after injury) Assess the use of BWSTT associated with electrical stimulation in peroneal nerve. The treatment lasted 3 months (3 times/week) with sessions of 1.5 h.	Individual with some ability to ambulate received benefits from BWSTT associated with electrical stimulation, improved gait speed.
Field-Fote and Tepavac (2002)	14 iSCI (male) 3 controls (male)	Patients SCI ASIA C, injury below T-10, average of 70 months after injury. 12 weeks of treatment (3 times/week) total of 36 sessions.	Patients walked at a speed 84% higher than the initial and improved coordination.
Postans <i>et al.</i> (2004)	12 iSCI (male) (acute phase)	Patients ASIA C e D. The treatment lasted 4 weeks	The group that received BWSTT obtained better results on

Table 1: Continue

		using BWSTT associated with electrical stimulation (5 sessions/week) for 25 min, just as occurred in the control period performed with conventional physiotherapy. Patients ASIA C, accomplished 68 sessions of BWSTT (3 times/week). Time of session was not reported. Started with 65±3% of body weight support.	performance and walking speed compared to control. In addition, spasticity and muscle strength have not showed differences after both treatments.
Stewart <i>et al.</i> (2004)	9 iSCI (male)		Increased muscle fiber area of type I and IIa. Improved lipid profile (decreased LDL). No change in body fat.
Phillips <i>et al.</i> (2004)	9 iSCI (male)	Patients ASIA C and developed the treatment using BWSTT for 6 months (3times/week) 68 total sessions. Started with 65±3% of body weight support.	Improved blood glucose regulation (increased glucose intolerance) and increased insulin sensitivity.
Behrman <i>et al.</i> (2005)	1 iSCI (male)	Patient, injury in C6-7, ASIA D, ambulation for three years with a rolling walker and right AFO brace. 45 sessions of locomotor training were performed, 5 sessions per week, 30 min. BWSTT training, 20 min. Walk on the ground and community ambulation.	Evolved from home ambulant with orthesis to community ambulation using crutches, improve gait speed, becoming more symmetrical, with the balance of the upper limbs, coordination and appropriate steps. The number of steps measured for 24 h also increased.
Field-Fote <i>et al.</i> (2005)	27 iSCI (male) (<1 year after injury)	Patients with injury above T-10, received treatment with BWSTT during 12 weeks (5 times/ week), 60 min/ session.	An improvement in walking speed, stride length and symmetry was observed.
Effing <i>et al.</i> (2006)	3 iSCI (male) (>4 years injury)	Patients, 2 ASIA C and 1 ASIA D performed BWSTT for 12 weeks (5times/ week) 30 min each session.	A discreet improvement was observed in quality of life.
Lucareli <i>et al.</i> (2008)	12 iSCI (male) (<1 year after injury) 12 controls (male)	12 patients iSCI, ASIA C and D accomplished 30 sessions (2 times/week) during 4 months with BWSTT and 12 patients received physical therapy in the control group with the same procedure.	Increased speed distance, cadence, stride length, total cycle time and decreased support time on the gait. The BWST was more effective than conventional physiotherapy on gait kinematic parameters.
Lucareli <i>et al.</i> (2008)	12 iSCI (male) (>1 year after injury)	Assessed the use of BWSTT in patients ASIA C e D, ambulant. Treatment lasted 4 months 30 sessions, 30 min each), (2 times/week.	There was improvement in the temporo-spatial parameters of gait, three showed no improvement in quality of life.
Behrman <i>et al.</i> (2008)	1 iSCI (4 ½ years) (male)	Training in BWSTT, ASIA C, injury in C-7, 3 months after injury, wheelchair dependent, LEMS 4/50. 16 months of treatment, 76 total sessions, 20-30 min of BWST.	Showed after the first month of treatment: voluntary steps, progressing with the ability to walk with a rolling walker. At the end of locomotor training, walking independently, with significant There was no change in LEMS score.
Musselman <i>et al.</i> (2009)	4 iSCI (male)	Assessed 4 SCI patients ASIA C. All patients started BWSTT treatment. After, 2 of them receive skills training (walking on different surfaces, gait training with obstacles, walking long distances and others) and the rest continued with BWSTT. In the third phase of treatment, reversed the order of treatment. Each treatment phase lasted 3 months, 1 h each session (5 times/week).	There was no improvement in static and/or dynamic balance. The walking speed improved during treatment with motor skills, higher than BWSTT.

Legend: AIS = American Spinal Injury Association impairment scale BWSTT = body weight treadmill training; LDL = Low Density Lipoprotein; Lower Extremity Motor Score (LEMS); iSCI = incomplete Spinal Cord Injury

The sample size probably did not allow a statistically significant difference, however the investigators were able to observe large differences in distance traveled and energy expenditure of the group that received BWSTT compared to conventional physical therapy group (Cunha *et al.*, 2002). In another study, 43 post-stroke patients received BWST treatment and 36 patients were treated with conventional gait training. Both groups were treated for 6 weeks (2 sessions per week, 20 min each). Investigators verified the balance, motor recovery, walking speed and strength. There were statistical differences for all parameters, with better results for BWSTT group. They conclude that increasing gradually the body weight is more advantageous and contributes to better balance and gait capacity when compared to conventional training on the treadmill (Visintin and Barbeau, 1998). Daly *et al.* (2004), studied 16 post-stroke patients over 12 weeks, 4 times a week, 90 min each session. They compared a group of 9 patients who were treated with BWSTT in combination to Functional Neuromuscular Stimulation (FNS) with Intramuscular (IM) electrodes (FNS-IM) to a group of 7 patients who received only BWSTT. Outcome measures were kinematics of gait swing phase. There were no statistical significant differences between groups, with no significant pre-/post-treatment gains in peak swing hip flexion. BWSTT had no significant gains in other gait components at post-treatment or at follow-up. BWSTT+FNS-IM group had significant gains in peak swing knee flexion and mid-swing ankle dorsiflexion that were maintained for 6 months.

In addition, in patients with CP, BWSTT also aided in gait and motor skills, posture, balance and improved scores on the Gross Motor Function Measure (GMFM) scale, in 6 out of 10 patients that cannot walk, demonstrating the effectiveness of BWSTT also in patients depending on the gait (Schindl *et al.*, 2000).

In PD patients, BWSTT was superior compared to conventional physical therapy treatment. Ten PD patients were investigated and statistical difference was observed between conventional physical therapy and BWSTT groups. An improvement in motor performance and mobility of gait were found, leading to an enhancement of activities of daily life (Miyai *et al.*, 2000).

With respect to iSCI, several studies showed significant clinical effects (Field-Fote *et al.*, 2005; Gardner *et al.*, 1998; Field-Fote and Tepavac, 2002; Wernig and Wernig, 1992; Wernig *et al.*, 1995; 1998; Nymark *et al.*, 1998; Behrman and Harkema, 2000; Protas *et al.*, 2001; Field-Fote, 2001; Postans *et al.*, 2004; Field-Fote *et al.*, 2005; Lucareli *et al.*, 2008; Behrman *et al.*, 2008; Musselman *et al.*, 2009; Phillips

et al., 2004; Behrman *et al.*, 2005). For instance, the study of Field-Fote *et al.* (2005) assessed gait of 27 iSCI patients (<1 year after injury, above T-10). After 12 weeks (5 sessions/week) treatment with BWSTT there was improvement in gait speed and step length and symmetry (Field-Fote *et al.*, 2005). Another study examined 12 iSCI patients (ASIA C and D) in acute phase. Each patient was his own control in second period. In the first period, they received conventional physical therapy and BWSTT, beginning with a withdrawal of 40% of body weight associated with FNS. The treatment lasted four weeks (5 sessions/week) with 25 min per session for both treatment periods. The findings of first period were superior compared to second period on performance and walking speed. However, spasticity and muscle strength were not significant different between periods of treatment (Postans *et al.*, 2004). Stewart *et al.* (2004) showed that after 6 months of treatment (3 sessions/week), iSCI patients (ASIA C) showed improvement in lipid profile with decreased LDL, increased muscle fiber area of type I and IIa, but no changes in body fat mass. Similar results were found by Phillips *et al.* (2004). They examined iSCI patients (ASIA C) and treated them with BWSTT for 6 months (3 times/week) with a total of 68 sessions, observing improvement in regulation of blood glucose (glucose tolerance) and increased insulin sensitivity.

CONCLUSION

iSCI is a severe neurological condition that causes serious compromises, such as gait disability. Most of studies of BWSTT showed better physiological and psychological effects than studies using conventional gait training. BWSTT appears to be more effective when combined with electrical stimulation. In contrast, no benefits were found for BWSTT in the improvement of muscular strength and bone density, spasticity and body fat. Moreover, BWSTT showed reduction in energy expenditure measured by oxygen consumption (VO_2^{\max}) and decrease in heart rate after training. These findings indicate decrease in chances of a traumatic event such as cardiac arrest or shortness of breath during training and decrease in fatigue during and after training. However, BWSTT does not seem to prevent loss of bone density in both acute and chronic phases of iSCI. Even though, BWSTT seems to be effective, safe and reliable method for functional rehabilitation of gait, there is still no sufficient scientific evidence to confirm it. Therefore, more controlled studies are required to better understand the efficacy of BWSTT in iSCI.

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