

PULMONARY FUNCTION IMPROVES IN PERSONS WITH PARAPLEGIA AFTER PARTIAL BODY WEIGHT SUPPORTED TREADMILL TRAINING: A PROSPECTIVE RANDOMIZED STUDY

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Abstract Objectives: To evaluate changes in Pulmonary Function Test (PFT) parameters in individuals with paraplegia following Partial Body Weight Supported Treadmill Training (PBWSTT).

Design: Randomized controlled trial.

Setting: Inpatient rehabilitation facility.

Participants: Adults with chronic SCI ($n = 42$).

Intervention: Patients were randomly allocated in CR group ($N = 20$) receiving Conventional Rehabilitation or in PBWSTT group ($N = 22$) receiving both Conventional Rehabilitation and PBWSTT for 4 weeks.

Main outcome measure(s): Changes in % predicted PFT parameter for the subject's age, sex and BMI.

Results: With PBWSTT, significant PFT changes were VC ($P = 0.009$), PEF ($p = 0.001$) and ERV ($p = 0.032$). In complete SCI, PEF ($p = 0.026$) improved, while in incomplete SCI VC ($p = 0.005$), ERV ($p = 0.029$), PEF ($p = 0.001$) improved with PBWSTT. In upper neurological level of injury (NLI) (T6-T11), PBWSTT improved PEF ($p = 0.004$) alone while in lower NLI (T12-L2), with PBWSTT both ERV ($p = 0.016$) and PEF ($p = 0.035$) improved.

Conclusions: With added PBWSTT most parameters including Vital Capacity, the global measure of PFT, improved significantly, especially in Lower NLI and incomplete SCI. The positive role of this noninvasive exercise based intervention in improving lung functions comes as an added benefit to the usual benefit of locomotion. This may encourage researchers to design future larger studies to validate it aiming the inclusion of PBWSTT in routine SCI rehabilitation protocols.

Key words: Partial Body Weight Supported Treadmill Training, PBWSTT, paraplegia, improvement, ventilation, PFT

Background

Spinal Cord Injury (SCI) with injury to the cervical and upper thoracic cord disrupts the function of the accessory respiratory muscles including abdominal muscles, thereby causing a reduction in lung function parameters (Katz et al., 2018). Pulmonary complications are a leading cause of death in chronic SCI (Garshick et al., 2005). Pulmonary function is compromised not only in quadriplegia but also in paraplegia, albeit to a lesser extent. However, there is very limited research available describing the pulmonary function status of paraplegia with lower neurological levels of injury (NLI), with MEDLINE search yielding only one study addressing the issue (Fugl-Meyer, 1971). The functions of accessory muscles of respiration including intercostals and abdominals are compromised both in case of complete or incomplete injury. Lower thoracic or lumbar NLIs are also involved, although the severity of impairment in lung functions reduces with the incompleteness of SCI and lower NLI since less number of respiratory muscles are affected than in upper NLIs and complete SCI (Schilero et al., 2009; Vázquez et al., 2013)

SCI causes restrictive changes in lung function, with reductions in vital capacity (VC), functional residual capacity (FRC), and expiratory reserve volume (ERV). These changes are most marked and have been widely studied in high SCI, especially in quadriplegia (Almenoff et al., 1995; Hemingway et al., 1958). Compromised lung function in paraplegia with lower thoracic or lumbar NLI, where accessory muscles of respiration, especially the intercostal muscles and abdominal muscles are significantly spared, is often considered negligible when compared to normal subjects (Hemingway et al., 1958). This is probably the reason why Medline search yields scanty literature addressing this issue. Vital Capacity (VC) has been found to be lower even in lower NLI (Hemingway et al., 1958). This is significant as VC is widely accepted as the single global measure of ventilator status in SCI (Roth et al., 1995). Expiratory muscle training in SCI patients resulted in improvement of pulmonary function only with resistance exercises in one study (Roth et al., 2010).

Partial Body Weight Supported Treadmill Training (PBWSTT) is a locomotor training modality beneficial for improving motor function of lower limbs in stroke, SCI, cerebral palsy, and some other similar conditions. PBWSTT involves repetitive facilitated stepping movement of the legs. Repetitive practice of motor tasks leads to Central Pattern Generator (CPG) activation at the spinal level in SCI when PBWSTT is used (Dietz, 2003). During PBWSTT training, repeated stepping on a treadmill provides sensory cues (Roy et al., 2012). Load or joint-related afferent input from hip joints is crucial for locomotor pattern generation in SCI, with neuroplasticity playing a major role in it (Van de Crommert et al., 1998).

It is already known that PBWSTT results in functional benefits to the core muscles as well as muscles of the lower limb in SCI. de Paleville et al. (2013) in a pilot study and Tiftik et al. (2015) in a study involving a mixed group of cervical, thoracic and lumbar SCI subjects found PBWSTT to be overall beneficial for improving Pulmonary Function Test (PFT) parameters in SCI. There is a possibility that this particular repetitive motor task can also modulate respiratory muscle functions through locomotor pattern generation in SCI patients with paraplegia. In this study, the study question is whether this particular repetitive motor task can also modulate respiratory muscle functions in SCI.

In this study, we specifically focused on paraplegia only, with NLI ranging from T6 and below. We compared the effect of PBWSTT on lung function in two groups, with one group receiving PBWSTT along with conventional rehabilitation, and the other receiving conventional rehabilitation alone. This study tries to address the lacuna in current knowledge to find out if PBWSTT is helpful to improve pulmonary function in SCI, especially if the neurological level of involvement is low. This study is unique as in Medline (PUBMED) search no other study was found to deal with the effects of PBWSTT on pulmonary function of persons with paraplegia exclusively.

Material and Methods

This prospective randomized trial was conducted between October 2018 and January 2020 in an Indian Government Medical University.

Subjects: Our study population comprised patients with paraplegia due to SCI who were admitted to the rehabilitation unit of a Medical University, which is the apex referral center of a Northern Indian province.

Sample Size calculation: The statistical software SPSS version 20 has been used for sample size calculation. Assuming p value <0.05 to be significant and considering the effect to be two-sided, we get $Z\alpha = 1.96$; assuming the power of the study to be 90% we get $Z1-\beta = 1.28$; considering an effect size (Difference in VC%) of 9.10 to be statistically significant we get $n > 2(Z\alpha + Z1-\beta)^2 \times SD^2/d^2$ we get $n = 19$. Hence a minimum of 19 patients will be taken in each group. Hence Total Sample Size will be 38.

However, we have taken 20 subjects in Group 1 and 22 in Group 2 as per our availability, both numbers being greater than the minimum required sample size.

$z\alpha$ (the Value of the standard normal variate at 5% error) = 1.96

$z1-\beta$ (the Value of the standard normal variate at 80% power) = 1.28

A related previous study by Tiftik et al. (2015) provides the following:

VC% Group 1 = 80.6

VC% Group 2 = 71.5

$d = \text{Effect Size} = (3.44 - 0.69) = 9.10$

SD = Pooled Standard Deviation Assumed to be 8.6

$n > 2(Z\alpha + Z1-\beta)^2 \times SD^2/d^2$

$= 2(1.96 + 1.28)^2 \times 8.62/(9.1)^2 = 18.76 \approx 19$.

Inclusion criteria: Hemodynamically stable adult patients with paraplegia up to 60 years of age with neurological level of injury (NLI) T6 (6th thoracic segment) or lower and between 3–18 months duration of injury were included in the study with informed consent after approval from Institutional Ethics Committee

Only those who completed Tilt Table Training and could maintain upright posture without suffering from symptoms of postural hypotension were eligible for the study. Thoracic 6th (T6) NLI was the highest since the

abdominal muscles get innervated by T6-L3(Lumbar 3rd) segments. Also, the external and internal intercostals get innervated most caudally till T11. Hence we divided our patients into two subgroups, the higher NLI group (T6-T11) where supply to both intercostal and abdominal muscles are affected, and the other subgroup being the lower NLI group (T12 to L3) where only abdominal muscles are affected.

Exclusion criteria: Patients with pre-existing musculoskeletal or neurological conditions other than SCI, pre-existing pulmonary diseases, spasticity more than grade 2 on the modified Ashworth scale that interferes with upright posture during locomotor training, and unstable vertebral injury were excluded.

Patients were randomly allocated by a computer-generated system to either of the two arms of the study, the PBWSTT group (n = 22) and the CR group (n = 20). One group received PBWSTT along with conventional rehabilitation (PBWSTT group). The other group of patients received conventional rehabilitation only (CR group).

Institutional Ethics Committee [Ref no. 94th ECMII B-Thesis/P-24; registration no. of IEC: ECR/262/Inst/UP/2013/RR-16] was taken. The procedures followed are in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, revised in 2000.

Exercise protocol: Conventional rehabilitation was performed by a single trained physiotherapist according to the guidelines of the Government of India – WHO collaborative program (2008–09) at CMC Vellore (*Guidelines for care of persons with Spinal Cord Injury in the community: Developed under the Government of India-World Health Organization Collaborative Programme (2008–09) at Christian Medical College; Vellore; India, 1/2009, p. XXXX*).

This included range of motion /stretching exercises, tilt table training, balance, endurance, coordination exercise, and gait training with appropriate orthoses. Bedside respiratory muscle exercise protocol was received by both groups (Vetkasov & Blanka, 2014).

Respiratory muscle exercises

1. “Bellows”: Rapid breath – rapid exhalation, pushes the abdominal and diaphragm. Initially recommended slower breathing (one breath for 2 sec.) and then adding time and speed of repetition. Patients are to begin with 5 rounds. The number of breaths or breathing cycles depended on the lungs and their abilities. After the patient could handle basic exercises every day two to three rounds were added until finally several 60 laps per session were reached. As soon as any sign of fatigue or hyperventilation could be detected, exercising was stopped, and not done until the next day when started with a lower number of repetitions.
2. Inhalation, then exhalation again and then without exhalation one more extra breath – patient asked to hold breath for about 3 seconds – exhale, exhale and a third time exhale to completely empty the lungs – again, holding the breath for 3 seconds and pressing on the diaphragm.
3. “Strong hug”: arms raised ahead, bent at the elbows, the gap between the fingers about 5 inches apart – rapid breath at that draw up arms to the body, as we would like someone to give strong hug – smooth exhalation and return to the starting position.
4. “Rowing”: breathe in, hands stretched forward – exhalation, the shoulder blades together, arms bent, elbows back, chest tighten.
5. “Butterfly”: arms raised ahead, bent at the elbows, shoulder blades together. Arms are to be pushed together slowly as the patient squeezes his chest in the middle. Exhalation during this part of the motion and the contraction is to be held for a second. The patient breathes in, returning to the starting position slowly as he inhales until chest muscles are fully stretched.

6. Push and pull” (on each hand): inhalation, hand tightens, as if to push the wall – exhalation, elbow bent as if you wanted to draw something.
7. Arms back of the head: inhale – elbows to push back. – Exhale – relax back.
8. Upright sitting: inhale – upper limbs out for the body – exhale – back, upper limbs change.
9. “Dumbbells”: inhale, hands up – exhale, hands go by the elbows to the body, as if the patient had dumbbells
10. Brügger sitting position: inhale – upper limbs lift, exhale – pull the knee to the chest.
11. Blending” (left / right): the starting position is arms raised ahead, palms together, shoulders down. Inhale – hold arms close to the body, exhale – arms upward. Note: as if the patient is mixing something in a big pot.
12. Brügger sitting position: inhale – put right/left hand, to the left/ right and down, body and head turn towards the hand, exhale – raise the hand and look at it.

PBWSTT group received 16 sessions (30 min/session; 4 days/week for 4 weeks) of PBWSTT with manual stepping assistance while being suspended by a harness (Robertson Harness, Henderson, NV) and body weight support system (Innoventor, St. Louis, MO) over a treadmill (Biodex Medical Systems, Shirley, NY) under supervision of a single trained Physiatrist. The level of weight support was adjusted to maximize bilateral limb loading without the knees buckling during stance. A single trained physiotherapist positioned behind the subject aided in pelvis and trunk stabilization, as well as appropriate weight shifting and hip rotation during the step cycle. This manual assistance was done to facilitate knee extension during stance, knee flexion, and toe clearance during swing. The treadmill speed was adjusted to promote the best stepping pattern at the given body weight load. Speed was maintained within a normal walking speed range (0.80–1.40 m/s). Body weight support was continuously reduced over the course of the training sessions as subjects increase their ability to bear weight on the lower limbs [Fig 1].



Fig 1. Showing Partial Body Weight Treadmill Training of a patient having paraplegia
Incentive spirometry: standard Ramson® 3 ball incentive spirometer was used.

We assessed all the respiratory parameters in the erect sitting position as recommended (Tiftik et al., 2015). Standard spirometry testing with Geratherm® Spiostik Complete apparatus which uses BLUE CHERRY® software platform for cardio-pulmonary function diagnostics, and single-use Spiraflow® flow sensor was performed by a single masked observer both before and after rehabilitation procedures. Vital capacity (VC), forced expiratory volume at one minute (FEV1), tidal volume (TV), expiratory reserve volume (ERV), peak expiratory flow (PEF) were measured as percent predicted for that individual's age, sex and BMI. Three acceptable spirograms were obtained and the result of the best attempt was collected as recommended (Alajam et al., 2019; Tiftik et al., 2015). Changes in each parameter of PFT over time were collected in both groups and were analyzed.

Continuous variables were expressed as means and standard deviations (SD) and compared across the groups using a one-way ANOVA/ unpaired t-test when data is normally distributed and by Mann Whitney U/ Kruskal Wallis H test when data is not normally distributed. Categorical variables were expressed as the number and the percentage of patients and compared across the groups by using Pearson's Chi-Square test for independence of attributes/ Fisher's Exact Test as appropriate. Association between continuous variables was estimated by using Pearson Correlation Coefficient. Multivariate analysis was done by using Multiple Regression. The statistical software SPSS version 20 has been used for the analysis. An alpha level of 5% has been taken, i.e. if any p-value is less than 0.05 it was considered significant.

Results

The 22 patients of PBWSTT group had a mean age of 28.2 ± 11.4 (23.2, 33.3) and of 20 patients in the CR group had a mean age of 27.1 ± 10.8 (22.1, 32.2) [$p = 0.551$].

Gender distribution of PBWSTT group was Male: Female = 18:4, in CR group 15:5 [$p = 0.714$].

Duration of injury (months) in PBWSTT group was 7.9 ± 2.5 (6.7, 9.0) and in CR group 9.4 ± 4.5 (7.3, 11.5) [$p = 0.388$].

Duration of hospital stay (days) in PBWSTT was 45.6 ± 16.9 (38.1, 53.1); in CR group 41.3 ± 17.16 (33.4, 49.2) [$p = 0.580$].

All these parameters indicate that the baseline demographic characters in both arms of the study were comparable.

Parameters like VC, ERV, PEF have significantly improved overall with PBWSTT additional to Conventional Rehabilitation as compared to Conventional Rehabilitation alone [Table 1].

Table 1. Overall changes in PFT parameters, expressed as percentage of the predicted value for age, sex and BMI, following designated protocol of rehabilitation: inter group comparison.

	Control (n = 20) Mean ±SD (CI)	PBWSTT group (n = 22) Mean ±SD (CI)	p value
Level of injury (T6/T7/T8/T9/T10/T11/T12/L1/L2)	2/2/0/0/4/6/0/3/3	0/0/0/2/2/8/2/4/4	0.323
ASIA (A/B/C)	8/7/5	14/4/4	0.305
Change in % predicted VC	0.4 ±8.5 (-3.6, 4.4)	10.2 ±11.6 (5.0, 15.3)	0.009
Change in % predicted FEV1	3.3 ±7.0 (0, 6.6)	3.6 ±18.3 (-4.5, 11.7)	0.156
Change in % predicted TV	3.4 ±13.14 (-2.7, 9.5)	7.9 ±7.6 (4.5, 11.2)	0.094
Change in % predicted ERV	2.1 ±8.9 (-2.1, 6.3)	10.9 ±13.7 (4.8, 17.0)	0.034
Change in % predicted PEF	1.3 ±2.8 (-0.02, 2.6)	5.1 ±4.0 (3.3, 6.9)	< 0.001

In patients with complete injury (ASIA A), there is significant improvement in PEF, while there is deterioration in FEV1 with PBWSTT.

In patients having incomplete injury (ASIA B and C), ERV and PEF improved significantly with PBWSTT [Table 2].

Table 2. Inter group comparison of lung volumes between patients having complete (ASIA A) and incomplete SCI (ASIA B and C). All lung volumes and capacities are expressed as changes in percentage of predicted values for age, sex and BMI.

	ASIA A			ASIA (B+C)		
	Control (n = 20) Mean ±SD (CI)	PBWSTT (n = 22) Mean ±SD (CI)	p	Control (n = 20) Mean ±SD (CI)	PBWSTT (n = 22) Mean ±SD (CI)	p
Change in % predicted VC	4.7 ±2.9 (2.3, 7.1)	6.9 ±7.8 (2.3, 11.4)	0.784	-2.5 ±9.9 (-8.8, 3.8)	16.0 ±15.1 (3.4, 28.6)	0.005
Change in % predicted FEV1	6.7 ±3.6 (3.7, 9.8)	-2.4 ±13.4 (-10.1, 5.3)	0.011	1.0 ±7.9 (-4.0, 6.0)	14.2 ±21.6 (-3.8, 32.3)	0.534
Change in % predicted TV	0.5 ±3.9 (-2.7, 3.7)	7.1 ±7.9 (2.6, 11.7)	0.054	5.3 ±16.7 (-5.2, 15.9)	9.1 ±7.5 (2.9, 15.4)	0.752
Change in % predicted ERV	1.2 ±4.0 (-2.1, 4.6)	5.6 ±7.4 (1.3, 9.8)	0.273	2.7 ±11.2 (-4.5, 9.8)	20.2 ±17.6 (5.6, 34.9)	0.029
Change in % predicted PEF	1.7 ±1.2 (0.8, 2.7)	3.9 ±4.5 (1.3, 6.4)	0.026	1.0 ±3.6 (-1.3, 3.3)	7.2 ±1.4 (6.1, 8.4)	0.001

Higher levels of lesions (T6-T11) show significant increase in FEV1 and PEF with PBWSTT.

In patients with lower levels of lesion (T12 and below) ERV and PEF significantly improved with PBWSTT [Table 3].

Table 3. Inter group comparison of lung volumes of patients having higher NLI (T6-T11) and lower NLI (T12 and below). All lung volumes and capacities are expressed as changes in percentage of predicted values for age, sex and BMI.

Neurological level(NLI)	Higher NLI (T6-T11)			Lower NLI (T12 and below)		
	Control (n = 20) Mean ± SD (CI)	PBWSTT (n = 22) Mean ± SD (CI)	p	Control (n = 20) Mean ± SD (CI)	PBWSTT (n = 22) Mean ± SD (CI)	p
Change in % predicted VC	1.3 ±6.8 (-2.7, 5.2)	8.0 ±9.5 (1.9, 14.0)	0.062	-1.7 ±12.2 (-14.4, 11.1)	12.8 ±13.7 (3.0, 22.6)	0.124
Change in % predicted FEV1	4.4 ±6.3 (0.8, 8.1)	3.2 ±13.5 (-11.7, 5.4)	0.013	0.7 ±8.5 (-8.2, 9.6)	11.8 ±20.5 (-2.9, 26.5)	0.513
Change in % predicted tidal volume	1.7 ±14.8 (-6.8, 10.2)	6.8 ±7.9 (1.8, 11.8)	0.076	7.3 ±7.8 (-0.9, 15.5)	9.1 ±7.5 (3.7, 14.5)	0.825
Change in % predicted ERV	5.3 ±7.1 (1.2, 9.4)	8.0 ±6.9 (3.6, 12.4)	0.406	-5.3 ±8.9 (-14.4, 3.8)	14.4 ±18.9 (0.9, 27.9)	0.016
Change in % predicted PEF	1.0 ±2.9 (-0.7, 2.7)	4.8 ±5.2 (1.5, 8.1)	0.004	2.0 ±2.7 (-0.8, 4.8)	5.4 ±2.1 (3.9, 6.9)	0.035

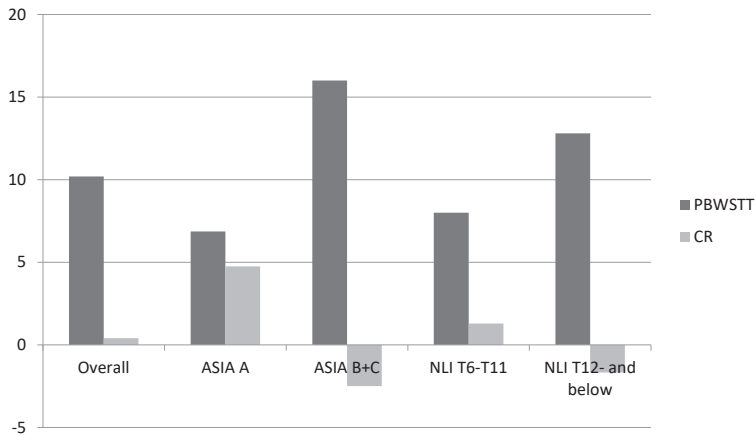


Fig. 2. Graphical representation of the change in % predicted VC in the PBWSTT group as compared to the CR group overall and in various subgroups according to NLI and completeness of SCI. The Y axis represents the % predicted change in VC.

Discussion

In this study, the PBWSTT and CR, the two arms of the study population were demographically unbiased and are comparable concerning parameters like age, gender, duration of hospital stay, and starting of rehabilitation following injury [Table 1].

A significant overall change in % predicted vital capacity (VC) in the PBWSTT group compared to the CR group [Table 2] was observed. Since Vital capacity is considered to be the single global measure of overall ventilatory status in SCI patients (Roth et al.,1995), the present study indicates that PBWSTT intervention improves ventilation in paraplegics. Our finding of improvement in VC is consistent with the findings of Tiftik et al. (2015)and other similar studies (Alajam et al., 2019).

Subgroup comparisons between complete Injury (ASIA A) and incomplete Injury (ASIA B and C) reveal that in incomplete paraplegia there is a significant improvement in VC following PBWSTT intervention [Table 2]. Between higher level paraplegics (T6-T11) and low paraplegics (T12 and below), no significant alteration of VC with PBWSTT was found [Table 3], which again was consistent with existing literature (Alajam et al.,2019)

Percent predicted Expiratory Reserved Volume (ERV), the maximum volume of air that can be exhaled from the end-expiratory position improved overall with PBWSTT. Subgroup analysis shows improvement in incomplete SCI, and also in lower NLI patients, which is expected, because in another study pulmonary function parameters show an inverse relation with completeness and level of lesion.

Percent predicted Peak Expiratory Flow (PEF), which is the maximum flow rate generated during forceful expiration, is an indicator of voluntary expiratory muscle activity. Here, PEF has improved consistently with PBWSTT in all subgroups too [Table 2],[Table 3].

Overall the change in % predicted FEV1 is statistically insignificant with respect to whether or not PBWSTT was added to conventional rehabilitation. However, there is a definite improvement with added PBWSTT in the higher NLI group (T6-T11), and deterioration in the complete SCI (ASIA A) subgroup. Such variability in the response

of FEV1 to PBWSTT cannot be explained despite extensive literature review, and can probably be attributed to our relatively low sample size.

No change in % predicted Tidal Volume (TV) was observed in either group. TV is a static lung volume that, along with other static and dynamic lung volumes is not affected much if the diaphragm and intercostal muscles work well in the absence of pulmonary disease (Hallett et al., 2021).

This study tried to address the lung function parameter changes in paraplegia, with special reference to low NLI. This issue has often been overlooked as it is presumed that in lower levels of lesions, the PFT findings more or less approximate that of a normal person (Fugl-Meyer,1971; Kokkola et al.,1975)

Why and how some changes at all occurred in PFT parameters in case of low thoracic and even lumbar level SCI after the intervention of PBWSTT added with conventional therapy in this series, is worthy of serious reflection. The explanation behind this may be in the emerging concept of 'neuroplasticity'. Neuroplasticity is the ability of the brain and spinal cord to modify their connections and function in response to environmental demands. Based on the plastic capabilities of the central nervous system, it is apparent that the motor system reorganization occurs spontaneously through synaptic reorganization, axonal sprouting, and neurogenesis after an injury, and after training including body weight supported assisted stepping (Knikou, 2012). One vital component of the molecular, anatomical, and functional changes associated with neuroplasticity is the spinal interneuron (SpIN) and its therapeutic targeting after SCI. The neuroplastic potential of SpINs after injury or disease makes these cells an attractive target for therapeutic interventions. Such interventions mostly include activity-based therapies, such as exercise and active rehabilitation. These recruit SpIN networks that play a significant role in generating locomotor patterns (Harkema, 2008; Roy et al., 2012). Recent pre-clinical studies also suggest that SpINs are recruited by respiratory training, in turn (DiMarco & Kowalski, 2013).

Literature review indicates that loss of supraspinal input results in a marked change in the functional efficacy of the remaining synapses and neurons of intra-spinal and peripheral afferent (dorsal root ganglion) origin (Lynskey et al., 2008) Greater motor recovery occurs in lumbosacral spinal cord lesions if it has been exposed to the afferent and intraspinal activation patterns that are associated with standing and stepping (Roth et al.,2010; Lynskey et al., 2008). Load- or hip joint-related afferent input seems to be vital for both locomotor pattern generation and the effectiveness of the training (Van de Crommert et al.,1998).

Even in SCI with paraplegia, disruption of supraspinal input to intercostal and abdominal motor neurons can cause compromised lung function despite an intact phrenic motor system and diaphragm. Flaccid paralysis of thoracic intercostals results in paradoxical chest wall contraction rather than expansion during diaphragm activity, with reduced ventilator efficiency(DiMarco & Kowalski, 2013; McMichan et al.,1980; Ledsome & Sharp,1981). Paralyzed abdominal muscles can lead to impaired cough-mediated clearance of airway secretions with associated atelectasis, infection, and compromised respiratory function (Cheng et al., 2006; Hoh et al., 2013; McMichan et al.,1980; Stiller et al.,1992). Therefore improved ventilation in SCI, in general, is the most important target of rehabilitation. Our result indicates that the addition of PBWSTT intervention is a simple step to address an unmet need for pulmonary rehabilitation in individuals with paraplegics. On this issue, to date, only two pilot studies by Soyupek et al. (2009) and de Paleville et al. (2013) with patients having cervical NLI and a prospective trial involving 52 patients having mixed NLI by Tiftik et al. (2015) have been conducted. Paraplegia, particularly lower NLI is comparatively common, hence this study highlights the need for validation of our findings in a large sample-size study.

Primary data collected by a single investigator was used which is the strength of this study.

Limitations of the study include small sample size, time constraints, and the fact that maximum inspiratory and expiratory pressures could not be tested because our setup doesn't come with a differential pressure transducer. Also, our setup has no provisions for VC or ERV measurement by nitrogen washout or body plethysmography which could be a significant limitation.

Conclusion

This study is the first prospective randomized study that deals exclusively with the issue of pulmonary rehabilitation in persons with paraplegia. The result of the study indicates the positive role of a noninvasive exercise based intervention like PBWSTT in improving lung functions, which comes as an added benefit even to those with lower neurological levels of lesion. In future, if validated by further larger studies, especially with more robust pulmonary function testing, this simple add-on intervention could be included in routine rehabilitation protocol of SCI patients to improve ventilation. Also, it might help future research to find out target areas for exploration of the scope of neuroplasticity in SCI.

What is already known on this subject

Most of the previous studies address issues related to ventilatory impairment of individuals with quadriplegia as their lung functions are more severely affected, but research on how to improve ventilation in individuals with paraplegia is sparse. There is only one study that included mixed upper and lower SCI patients which shows some benefit with PBWSTT in pulmonary function.

What this study adds

- Partial Body Weight Supported Treadmill Training, which otherwise may be beneficial for locomotor training in SCI is also found to improve lung function. This finding supports a previous work (Tiftik et al., 2015).
- Individuals with paraplegia even having lower neurological level involvement show better lung function when PBWSTT is included in rehabilitation protocol. No such study has been done previously to the best of our knowledge, involving individuals with paraplegia having lower neurological level involvement exclusively.
- Neuroplasticity, signaled by the sensory cues generated by process of repeated stepping and load bearing while performing PBSWTT and locomotor-respiratory coupling may have some role in improvement of ventilation in individuals with paraplegia with lower neurological level involvement by strengthening abdominal and intercostals muscles mostly, It may be a subject of future research.
- PBWSTT thus may be included as a simple noninvasive training regimen that may be included even in patients having lower neurological level spinal cord lesion. This may bring on an add-on benefit of ventilatory improvement over the usual locomotor benefits without adverse effects.

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