Curr Phys Med Rehabil Rep (2017) 5:99–107
DOI 10.1007/s40141-017-0155-8

SPINAL CORD INJURY REHABILITATION (CL SADOWSKY, SECTION EDITOR)

Whole Body Vibration for People with Spinal Cord Injury: a review

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Published online: 3 July 2017

Abstract
Purpose of Review The purposes of this review are to summarize recent findings related to use of whole body vibration for people with spinal cord injury, explain their significance for clinical practice, and outline future areas for research.
Recent Findings Positive outcomes identified by whole body vibration research performed to date are that it appears to be safe and well tolerated, that it may improve tolerance to upright standing via increased muscle oxygenation and improved maintenance of blood pressure in the upright standing position, and that it improves the patient's body awareness during treatment.
Summary Clinical decision-making at this time should be guided by careful consideration of existing studies in light of the limited but emerging research in this area.

Keywords Whole body vibration · Spinal cord injury · Spasticity · Osteoporosis · Bone mineral density · Cardiovascular function

Introduction

Whole body vibration (WBV) has been described in the rehabilitation science literature as an intervention used to care for patients with various conditions across the lifespan [1–10]. In physical therapy, WBV has been promoted for use in individuals with spinal cord injury (SCI) for the following six reasons: to increase bone mineral density (BMD) [11, 12, 13•, 14, 15], improve or maintain cardiovascular function (CVF) [16, 17•, 18•, 19•], reduce spasticity [20–22], progress walking speed [23], enhance neuromuscular function [24, 25, 26•, 27–29], and improve tolerance to upright positioning and exercise [30]. Additional research has investigated the subjective response to WBV [31]. The mechanisms of WBV for SCI are not fully understood at this time. However, it is believed that the rapid stretch to the muscles and physical displacement of the body occurring during WBV cause muscles to activate, thereby limiting postural sway and other forms of displacement caused by the vibration [24, 30, 32]. As activity-based therapies become more prevalent in the rehabilitation of SCI, WBV may be an intervention to enhance outcomes in therapeutic settings. Initial findings outlined herein demonstrate its ability to modulate some of the deleterious effects of SCI while enhancing certain functional outcomes. The purposes of this review are the following: (1) to summarize recent findings related to the use of WBV for people with SCI, (2) to explain their significance for clinical practice, and (3) to outline future areas for research.

Literature Search

The terms "whole body vibration" and "spinal cord injury" were used to conduct the initial searches in Pubmed, Scopus, EMBASE, and CINAHL with the limiters of human-subject studies, conducted in the past 10 years and published in English. Additional literature was identified from the reference lists of articles found in the original search.

Articles investigating WBV were incorporated regardless of how the vibration was delivered. This involved subject

This article is part of the Topical Collection on *Spinal Cord Injury Rehabilitation*

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positions of standing, semi-squat, reclined on a tilt table, and seated. Also, both forms of WBV production, vertical and side alternating, were included. Vertical means that the entire vibration plate moves up and down at the same time, whereas side alternating describes vibration created by the plate tipping from side to side rapidly. In both forms of vibration, the total displacement was between 0.6 and 5 mm. Finally, while recent evidence about WBV for SCI is currently limited to the areas outlined in this paper, it is important to note that the purported benefits stand to impact body function, activity, and participation, all important aspects of the International Classification of Function model [33].

Bone Mineral Density

Evidence suggests that for the first 2 to 8 years following SCI, BMD rapidly declines [1, 34–42] and may be mediated by additional variables including level of injury and sex [43]. Changes have been noted in both cortical and trabecular bone and vary by the bony site studied [43–45]. Neuroendocrine mechanisms for these changes include abnormalities in calcium, parathyroid/vitamin D hormones, sex steroid levels, deoxypyridinoline, and alkaline phosphatase [46, 47]. Although bone loss eventually may reach a steady state, the decline in BMD has been linked to debilitating comorbidities [48] from the resulting sublesional osteoporosis [49–51]. One consequence, pathological fractures, are between 1.5 to six times more common for people with SCI compared to their non-spinal cord injured counterparts [40, 52–55]. Currently, there is not a gold standard treatment for BMD loss in people with SCI; however, investigation into the effects of WBV on BMD is ongoing [1, 8, 9, 35]. Efforts to date include determining best positions and WBV parameters to improve BMD, as well as attempts to quantify the load bearing and vibratory forces encountered by the body during WBV [12, 13•, 27].

Research in this area is notable for small study populations and the lack of randomized, controlled study designs. For example, a single subject case study compared three phases of a progressively phased rehabilitation program on BMD and lean tissue changes in a woman with a chronic, T10, incomplete SCI [11]. Each phase lasted 10 weeks and the phases were separated by 7-week long inter-phase periods. The first two phases were structured as follows: standing in a supported standing frame (phase 1) and supported standing followed by seated exercise with feet on a WBV plate (phase 2). Both of these phases resulted in an overall loss of BMD. The third phase included supported standing on a vertical vibration plate and resulted in increases in BMD and lean body mass and a decrease in body fat.

A separate experiment studied alternate arm positions to maximize lower extremity load bearing during supported standing versus supported standing with WBV [12]. Eleven individuals with chronic, motor complete SCI demonstrated that when standing in a supported stander, about 10% more weight was borne through the lower extremities when the subjects' arms were at their sides than when the arms were positioned on the standing frame tray. Further comparisons of arm position with and without WBV found no difference in the effect of WBV on lower extremity weight bearing with regard to arm position. Although this study was limited to people with paraplegia, it is unlikely that many people with motor complete tetraplegia would tolerate supported standing with or without WBV in the absence of arm support, nor would it be safe for those with shoulder subluxation.

While patient position is important, so are the WBV parameters used. Alizadeh-Meghrazi et al. [27] sought to determine the combination of frequency, amplitude, and posture that would best transmit vibratory forces to the lower extremities while limiting the same forces to the head [27]. Their rationale was that vibration forces transmitted to the lower extremities may aid in the formation of cortical bone and osteoblastic activity that would be beneficial post-SCI. However, vibration forces transmitted to the head have been linked to the temporary side effects of headaches and nausea, both of which could deter long-term adherence to WBV interventions. Using skin-mounted accelerometers to measure vibratory transmissions, the investigators compared a total of 19 WBV parameter combinations over two devices in males with and without chronic SCI. Subjects stood in a supported standing frame situated over one of two vertically vibrating plates. Overall, they found that combining a frequency of 45 Hz, amplitude of 0.6 mm, and a knee flexion angle of 140 degrees best met the criteria for optimizing lower extremity vibration while limiting vibration to the head. Since not all WBV devices allow for this combination of parameters, and actual vibratory transmission varies by device, these experiments should be re-evaluated on other WBV devices.

Despite the above-described efforts to elucidate the best standing conditions, it appears that even the duration of treatment required to effect change may be in question. Wuermser et al. [13•] found no change in BMD, bone microstructure, or serum markers of osteoblastic/osteoclastic activity with a 6-month, home-based program that included 20 min of WBV, 5 days per week [13•]. Although the original study design called for a control group, this was eventually deemed impossible due to recruitment difficulties. Nonetheless, nine subjects self-reported their compliance with the study protocol. Outcome measures included dual-energy X-ray absorptiometry of the proximal femur and high-resolution peripheral quantitative computed tomography of the distal tibia. Recent evidence demonstrates that the areas of the greatest bone loss post-SCI are the distal femur and proximal tibia [37–39, 46, 49]. As a result, it may be useful to repeat this study investigating these most depleted areas and including a control group. The study authors speculated that a longer treatment

duration may be needed to demonstrate the changes they were seeking [13•]. Additionally, they stated that a much larger sample would be needed to demonstrate adequate power for this research question. Finally, they explained that as some of the subjects were only 2 to 3 years out from their injury, it is possible that the intervention effect was masked by the bone loss that would be normally occurring in this stage. If that were true, it is possible that the BMD decline could have been worse, but was mitigated by the implementation of WBV. Limiting future studies to participants who have been injured for at least 4 years and are outside of the window of the most rapid bone loss may be useful in the future.

Cardiovascular Function

People with acute and chronic SCI have physiologic impairments that limit their ability to make the typical and necessary adjustments to hemodynamics, muscle oxygenation, and oxygen consumption [56]. These effects begin shortly after injury [57] and continue to the chronic phase [56]. Low frequency WBV has been shown to increase oxygen uptake and peripheral blood flow in able-bodied adults and is of particular interest as a treatment for people with SCI [3, 58–60].

In 2014, Yarar-Fisher et al. compared acute effects of WBV on hemodynamics, muscle oxygenation, and oxygen consumption in people with and without chronic, motor complete SCI [19•]. Those with SCI were matched for age, gender, and activity level with non-SCI subjects. Using a cross-over, repeated measure design, the authors investigated changes in heart rate, mean arterial pressure, stroke volume, cardiac output, and oxygenated, deoxygenated, and total heme concentrations over the course of the treatment from baseline through post-intervention. These metrics were tested with 30, 40, and 50 Hz WBV protocols. While both groups experienced significant increases in oxygen consumption and muscle oxygenation, these effects were small and not likely to be clinically significant for people with SCI. However, they also observed significant and meaningful improvements in lower extremity blood flow and functional improvements in orthostatic tolerance, which would be beneficial in clinical rehabilitation settings. Future research on the specific protocol that would optimize upright tolerance is warranted.

One group of investigators has studied the acute and chronic effects of WBV on blood flow and neuromuscular activity with and without pairing WBV with neuromuscular electrical stimulation (NMES). In 2011, Herrero et al. performed a cross-over trial to look at mean and peak blood flow velocity in the femoral artery and electromyographical (EMG) activity in the vastus lateralis and medialis [16]. Testing occurred before and during 3 min of WBV administered at 10, 20, or 30 Hz with or without rest breaks over a total of eight sessions. Each of the frequencies resulted in increases to leg blood flow velocity and EMG activity. However, the 20 and 30 Hz frequencies resulted in the greatest changes. The inclusion of rest breaks between each minute of WBV did not result in blood flow or EMG differences compared to constant WBV for 3 min without rest. None of the parameter combinations resulted in changes as large as are typically seen in subjects without SCI. It is important to note that participants in the studies conducted by this lab were simultaneously undergoing regular rehabilitation treatment and may have been better conditioned to tolerate the study protocol than less physically active individuals. However, those sessions were relatively standardized, as were the study procedures, including that study activities always occurred before rehabilitation treatments on a given day.

The same investigators compared the acute and chronic effects on blood volumes and other related factors when combining WBV with NMES to the gastrocnemius [17•, 18•]. To study the acute effects of four different treatment conditions on popliteal artery mean blood flow, peak blood flow, and skin temperature, a randomized cross-over study was designed for people with motor complete SCI [17•]. Subjects received each of four conditions (WBV alone, NMES alone, WBV and NMES simultaneously, and bouts of WBV for 30 s followed by 30 s of NMES) in random order. Changes were tracked from baseline through post-intervention and indicated that the simultaneous WBV/NMES condition produced the greatest increase in blood volumes during and after the intervention and resulted in the greatest increase in skin temperature.

To study chronic adaptations related to these interventions, 17 subjects with motor complete SCI were enrolled in a randomized controlled study in which they were followed for a total of 20 weeks [18•]. The experimental group received 30 sessions of WBV with NMES and demonstrated significant improvements in popliteal artery resting diameter and blood flow which were not observed in the control group. Resting diameter remained significantly improved at post-intervention testing 8 weeks later. These findings also help to answer the question about subjects receiving regular, concomitant rehabilitation therapies during the study period. The control group remained effectively the same with regard to blood flow and resting arterial diameter during the study period, despite receiving 10 monthly therapy sessions of 2 h each. Additionally, gastrocnemius muscle thickness improved in the experimental group but was not maintained at the post-intervention follow-up.

Further study about the duration of improvement in blood volume and skin temperature using various WBV/NMES protocols might inform a safe and simple treatment program for people with SCI who often struggle with temperature dysregulation and poor peripheral perfusion. These individuals are at risk for developing devastating comorbidities as a result. Also, if future studies showed that improvements in muscle thickness could be maintained either with a different protocol or the

continuation of the above-outlined WBV/NMES intervention, it could provide a method to increase muscle bulk for reduced incidence of insulin resistance and other metabolic disorders that are common in the SCI population.

Spasticity Reduction

The mechanisms for spasticity occurring after SCI are believed to be due to alterations in the spinal reflex circuitry [42, 61–63]. These alterations occur when the spinal cord neural pathways are interrupted which interferes with appropriate signal modulation and maintenance of normal muscle tone during quick movements. Clinicians have long reported research and anecdotal findings that vibration, including WBV, reduces spasticity in people with SCI [32, 64]. Many aspects of this phenomenon, including the dose-response relationship of this effect have not been fully quantified yet, but are under investigation. Elucidation of these effects would be valuable for clinicians and patients since spastic hypertonia is known to interfere with the production of efficient functional movement patterns.

To investigate the dose-response relationship component, a study of 14 subjects (six with SCI) revealed that passive standing with WBV temporarily inhibited the soleus H-reflex [22]. The extent of inhibition differed between subjects with and without SCI, with the spinal cord injured subjects returning to baseline H-reflex sooner (average 36 s). Although the effect was short-lived, WBV was able to modulate H-reflex activity in this small subject set.

A systematic review conducted in 2014 investigated the use of vibration specifically for improvement of spasticity in people with SCI [20]. The review included focal vibration and whole body vibration experiments conducted in this population. Unfortunately, only one article about WBV by Ness et al. [21] met the review criteria and is discussed below.

To investigate the effects of WBV on quadriceps spasticity, 16 people with chronic SCI were recruited by Ness et al. [21]. Using the pendulum test, a gravity-provoked stretch test, quadriceps spasticity was assessed before and after standing WBV treatments. Comparisons were made between participants who were and were not using anti-spasticity medications during the trial period. A significant and lasting effect was noted, even for patients taking anti-spasticity medications. This indicates that WBV may improve quadriceps spasticity in this population beyond what can be accomplished with pharmaceuticals alone. Clinicians who use WBV to modulate spasticity in preparation for training functional movement and activity patterns may find this meaningful. The authors suggest further studies that compare individuals managed by anti-spasticity medications to individuals managed with WBV alone. Furthermore, while this study found that the effects of WBV on spasticity may last as long as 8 days, additional studies to quantify the effect duration in this population would be useful to inform clinical decision-making.

Walking Function

Vibration has been shown to be a possible method for stimulating central pattern generators of locomotion. A pilot study by Ness and Field-Fote found that 12 sessions of vertical WBV yielded increases in walking speed similar to those gained with locomotor training in 17 individuals with incomplete SCI [23]. Additional improvements were noted in cadence and bilateral step length. While 10 of the 17 subjects demonstrated changes of greater than 0.05 m/s, and the mean walking speed improved by 0.062 m/s ($p < 0.001$), the effect size was still considered small. The investigators were able to perform a follow-up of one subject 5 weeks post-intervention. This subject demonstrated continued gains in walking speed.

The authors suggested future studies related to WBV and walking speed should include randomized controlled trials and longitudinal measurements to determine the durability of the improvements seen with WBV in people with SCI. Based on the information available in conference proceedings and at clinicaltrials.gov, it appears that there are currently two national trials that are recruiting subjects to further investigate the effects of WBV on gait parameters in people with SCI.

Neuromuscular and Neuroendocrine Effects

There is strong to moderate evidence demonstrating improvements in neuromuscular performance and neuroendocrine function with WBV for trained and untrained adults including post-menopausal women [65–71]. The complex neuromuscular and neuroendocrine problems people with SCI often develop make WBV an intervention of significant interest [42, 45, 72–74]. While studies in the past 10 years that specifically investigate WBV's neuroendocrine effects were not found, several studies in that timeframe describe neuromuscular function in SCI with WBV treatment.

A review article specifically describing the effects of WBV on neuromuscular performance was published in 2016 [24]. The authors generally concluded that the current WBV evidence is insufficient in the area of neuromuscular performance for people with SCI; however, they did note that the likely effective range for WBV parameters in SCI is a frequency of 10–50 Hz, an amplitude between 0.6 and 4 mm, and 10–40 degrees of knee flexion during standing WBV. Although it would be beneficial to further narrow the range of these parameters, it does provide clinicians with guidelines that have been used safely across multiple studies.

Additionally, a few articles contributed key information and could hold promise for future study. Bosveld and Field-Fote noted a small but meaningful increase in isometric quadriceps strength in a study of 25 people with motor-incomplete paraplegia who underwent a single session of WBV compared to the sham group in a randomized controlled trial [26•]. They noted that effects were potentially tempered by the small sample size and parameter selection. Parameters included high frequency (50 Hz) and low amplitude (1–2 mm). Other parameters may yield greater results including increasing intervention frequency and duration.

A study that used a much longer duration of intervention observed that while passive standing with WBV induced lower extremity EMG activity in males with thoracic, motor complete SCI, it did not result in increased cross-sectional area or density of the lower extremity musculature [28]. The study involved 40 weeks of thrice weekly, 45-min sessions of WBV during passive supported standing in seven men with chronic SCI (≥2 years).

In another study, the specific parameters that yielded the greatest lower extremity EMG activity were investigated [29]. Small samples of able-bodied and spinal cord injured individuals were compared on two WBV devices, altering the variables of frequency, amplitude, and joint position. While not all variables can be accommodated across WBV devices, the variables that produced the most change, amplitude and frequency are readily adaptable on most devices. This study found the most EMG activity in individuals with chronic, mostly motor complete SCI when a high frequency (45 Hz) and low amplitude (1.2 mm) were combined and applied in a supported standing position. Interestingly, this finding held true for both able-bodied subjects ($n = 6$) and those with chronic SCI of at least 1 year ($n = 4$). All but one of the subjects with SCI had motor complete lesions. A clinically important observation was that body position in people with upper motor neuron lesions should allow for some knee flexion to reduce extensor spasms and synergies during WBV. While the study sample was small, the use of the study's optimized parameters could inform parameter selection in future studies aiming to increase EMG activity in this population.

EMG activity is important, likewise, is carryover of muscle activity to function. Asakawa et al. performed a pilot study to determine the impact of WBV on static seated balance in 12 people with AIS C or D SCI [30]. WBV was applied to the subjects' feet while in a supported squat position. Pre- and post-testing was performed using a force plate to measure postural sway. This single WBV session demonstrated improvement in medio-lateral and antero-posterior sway with eyes open and eyes closed in only the experimental group. Future research in this area might seek to quantify the duration of neuromuscular effects following WBV treatment, identify the optimal treatment parameters, and understand the underlying mechanisms.

Tolerance to Upright Positioning and Exercise

2011 marked the first study to investigate WBV in people with SCI using a tilt table modified to include a vibration plate [16]. The research team believed that the adaptable angle (45°) of the tilt table allowed for improved tolerance to the procedure, but may have been an impediment to optimally improving blood flow (see cardiovascular effects section of this paper). Further study should determine the benefits gained from progressive angles of inclination that more closely approximate full, upright standing, and the corresponding subject tolerance versus cardiovascular benefits. Finally, given that these experiments combined WBV and NMES, additional inquiry should determine the contributions of each intervention on the acute and chronic benefits described and their mechanisms.

Subjective Response to Treatment

With any intervention, it is important to consider factors related to patient comfort and overall subjective responses to the treatment. Interventions with a large proportion of negative side effects or significant barriers to participation are likely to limit short- and long-term intervention compliance and rehabilitation engagement. While none of the above referenced studies reported any generalized intolerances or safety issues with WBV in their subject populations who had SCI, one study looked specifically at the tolerability and subjective responses to various WBV protocols by comparing people with SCI and matched groups of people without SCI [31]. Overall, it was noted that the subjects with SCI were able to tolerate the WBV protocols better than those without SCI. While non-SCI subjects shared that the WBV was at times "annoying" or "uncomfortable," the subjects with SCI reported more positive statements including that WBV offered a "stretch [to] their leg muscles." Barriers to transfer in and out of the WBV devices did not impact device preference among subjects with SCI. This study speaks to the general feasibility, safety, and tolerability of WBV for people with SCI.

Conclusions

Limitations to the current research include that the heterogeneity of study aims and protocols makes it difficult to draw conclusions or identify specific parameters to best improve the myriad of impairments seen status post-SCI. A summary of the evidence excluding reviews and case studies has been compiled in Table 1.

Interventions that combine WBV with NMES appear potentially promising but require further evaluation of the specific parameters that will yield the greatest benefit and of the

Table 1 Summary of original, non-case study experiments investigating whole body vibration (WBV) in people with spinal cord injury (SCI) in the past 10 years

Proposed benefit	Author	Study type and participant information	Parameters	Major outcomes
Bone mineral density	Bernhardt et al. [12]	Pilot *n* = 11 male or female, AIS A or B, DI = 2–26 years	0.3 g amplitude, 34 Hz frequency, VV Compared supported standing with/without arm support, and with/without WBV	Arm position significantly impacts total weight bearing during supported standing WBV increased oscillation of load bearing in both arm positions
	Wuermser et al. [13•]	Pilot *n* = 9 male or female, AIS A or B, DI = 2–27 years	0.3 g amplitude, 34 Hz frequency, VV 20 min/day, 5 days/week, for 6 months	Larger, longer, controlled studies with strict adherence monitoring may be needed to demonstrate BMD changes in people with SCI of this duration of injury.
	Alizadeh-Meghrazi et al. [14]	Pilot *n* = 5 male, AIS A-C, DI > 1 year, *and n* = 7 male, non-SCI controls	Combinations of the following: Knee angle (degrees): 140, 160, 180 Frequency (Hz): 25, 35, 45 Amplitude (mm): 0.6, 1.2 Two WBV devices trialed: both VV Duration: 2 min per parameter combination	The parameter combination with the best leg vibration and least transmission to the head was 45 Hz, 0.6 mm, and 140° knee flexion and was well tolerated by subjects with SCI
Cardiovascular function	Herrero et al. [16]	Pilot, cross-over design *n* = 8 male or female, AIS A, DI = 2–24 years	Frequency: 10, 20, 30 Hz Intervention: constant, intermittent Duration: 3 min per parameter combination	Higher frequency (20 Hz, 30 Hz) WBV demonstrated increased leg blood flow and muscle activation safely in this study population
	Menendez et al. [17•]	Randomized cross-over *n* = 10, male or female, AIS A or B, DI = 4–29 years	4 protocols of WBV (10 Hz, 5 mm) and/or NMES (400 μsec, 8 Hz): 1. WBV 2. NMES 3. WBV/NMES simultaneously 4. WBV followed by NMES	WBV and ES delivered simultaneously in sitting produced the greatest increase in mean blood velocity and peak blood velocity of the popliteal artery and calf skin temperature, but the individual effects of each intervention were not quantified
Cardiovascular function (cont.)	Menendez et al. [18•]	Randomized two-group parallel *n* = 17 male or female, AIS A or B, DI = 4–29 years	Experimental group received 30 sessions of 10 min each of WBV (10 Hz, 5 mm) with ES (400 μsec, 8 Hz) in a seated position over 12 weeks	Compared to controls, experimental group demonstrated increases in popliteal artery resting diameter and blood flow and in gastrocnemius muscle thickness
	Yarar-Fisher et al. [19•]	Cross-over repeated measures *n* = 11 male, AIS A or B, DI = 6–26 years and 10 male non-SCI controls	3 sessions per subject involved supported standing with WBV (30, 40, or 50 Hz)	WBV did not alter heart rate, cardiac output, stroke volume, or total blood oxygenation but did result in more stable blood pressure during standing for study participants with SCI
Spasticity	Ness and Field-Fote [21]	Pilot *n* = 16 male or female, AIS C or D, DI > 1 year	WBV (50 Hz, 2–4 mm, VV) delivered in 4 bouts of 45 s each during 12 sessions over 3 weeks	A significant reduction in quadriceps spasticity was noted following WBV and lasted at least 8 days
	Sayenko et al. [22]	Pilot *n* = 6 male, AIS A-D, DI = 6–26 and *n* = 8 male, non-SCI controls	WBV (35 Hz, 1 mm, VV) delivered for 1 min in supported standing	WBV during supported standing temporarily reduced the H-reflex magnitude of the soleus in subjects with SCI to a lesser degree than for controls
Walking function	Ness and Field-Fote [23]	Pilot *n* = 17 male or female, AIS C or D, DI = ≥ 1 year	WBV (50 Hz, 2–4 mm, VV) delivered in standing in 4 bouts of 45 s each over 12 sessions in a 4-week timeframe	Walking speed increased significantly overall. One subject completed latent follow-up testing, with continued speed improvement 5 weeks post-intervention
Neuromuscular effects	Bosveld and Field-Fote [26•]	Randomized controlled trial *n* = 25 male or female, AIS C or D, DI = 1–35 years	Experimental group received WBV (50 Hz, 2 mm, VV) in 4 bouts of 45 s each during one session in a standing squat position. Control group assumed same position for same duration without WBV	One treatment session of this intervention resulted in larger maximal quadriceps force production in the experimental group; however, this did not carryover to functional task performance
	Alizadeh-Meghrazi et al. [29]	Pilot *n* = 4 male, AIS A or C, DI > 1 year *and n* = 6 male, non-SCI controls	Combinations of the following: Knee angle options: 140, 160, 180 Frequency options (Hz): 25, 35, 45 Amplitude options: (mm): 0.6, 1.2 Two WBV devices trialed: both VV	Electromyographic activity was most consistently produced using the parameter combination of 45 Hz and 1.2 mm in subjects with and without SCI
	Asakawa et al. [30]	Randomized controlled trial *n* = 12 male or female, AIS C or D, DI > 6 months.	WBV (30 Hz, 3 mm, VV) delivered in 4, 45-s bouts in modified sitting position to experimental subjects, versus no WBV for controls	WBV improved static sitting balance and decreased postural sway after one session

ASIA American Spinal Injury Association, *AIS* ASIA Impairment Scale, *DI* duration of injury, *VV* vertical vibration

different outcomes that may be appreciated between various muscles and WBV/NMES combinations.

Specific areas for future research were outlined in each section of this review, but generally include larger sample sizes and the implementation of longitudinal studies to quantify the durability of results.

Positive outcomes identified by the WBV research performed to date are that it appears to be safe and well tolerated, that it may improve tolerance to upright standing via increased muscle oxygenation and improved maintenance of blood pressure in the upright standing position, and that it improves the patient's body awareness during treatment.

Clinical decision-making at this time should be guided by careful consideration in light of the limited but emerging research in this area. While short-term WBV using the parameters described does not appear harmful in this population, its actual efficacy for each of the above-outlined uses remains to be seen.

Compliance with Ethical Standards

Conflict of Interest Cara Felter declares that she has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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