

# Effects of Partial Body Weight Supported Treadmill Training on Children with Cerebral Palsy

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**Purpose:** The purpose of this literature review was to investigate the effects of partial body weight supported treadmill training (BWSTT) on gross motor function, balance, gait speed, and endurance in children with cerebral palsy (CP). **Summary of Key Points:** Larger numbers of preschool and school-aged children have been studied compared with infants and toddlers. More evidence exists regarding the efficacy of BWSTT on endurance, gait speed, and gross motor function related to ambulation than on balance in children with CP. Longer and more intense BWSTT protocols may lead to better results. **Statement of Conclusions:** BWSTT has not been studied extensively in children with CP. Current evidence suggests that intensive and prolonged BWSTT may be a safe, effective, and beneficial treatment intervention for the attainment of walking, improvement of gait speed, and improvement of endurance for children with different types and degrees of CP. (*Pediatr Phys Ther* 2009;21:12–22) **Key words:** *body weight, cerebral palsy, child, exercise therapy/instrumentation, exercise therapy/methods, human movement system, orthotic devices, physical therapy, review article, walking, weight-bearing*

## INTRODUCTION

Cerebral palsy (CP) is the diagnosis most frequently encountered by pediatric physical therapists.<sup>1</sup> During the past 40 years, there has been a worldwide rise in prevalence of CP from 1.5 per 1000 live births in the 1960s to about 2.5 per 1000 live births today.<sup>2</sup> During this period, the proportion of infants with low birth weight increased from 32% to 50%, diplegia decreased and hemiplegia increased. Of the children who were diagnosed with CP, 72% to 91% were found to have spastic CP.<sup>2</sup> As many as 90% of children with CP present with difficulties during ambulation.<sup>3</sup>

Children with CP at a young age show different motor patterns compared with infants developing typically. Their movements lack fluidity, are less frequent, are monotonous, and are poorly differentiated.<sup>4</sup> Gait of children with CP is characterized by excessive muscle co-contraction, al-

tered joint kinematics, and a lack of postural reactions.<sup>5</sup> Ambulation plays a central role in healthy bone development<sup>6</sup> and cardiopulmonary endurance<sup>7</sup>; and children who are able to ambulate are more accomplished in activities of daily living and social roles than children who use a wheelchair.<sup>8</sup> Consequently, walking attainment is often an important functional goal for children with CP.

Partial body weight supported treadmill training (BWSTT) is one method used in neurological rehabilitation of adults and children that provides task-specific gait training with multiple repetitions and active participation of the client, which has been demonstrated to enhance motor learning.<sup>9–11</sup> Commercial BWSTT systems come in different sizes, from child to adult, and can be placed over an existing treadmill as long as it is of sufficient width. Additional scales are available to measure the amount of weight support given to the patient on one or both sides of the body.<sup>12</sup>

The reciprocal walking motion on the treadmill is thought to be controlled at least in part by the spinal cord, which can function in the absence of higher brain center function.<sup>13</sup> Reciprocal stepping is considered to be largely organized by networks of sensory and motor neurons within the spinal cord, which are referred to as central pattern generators (CPGs).<sup>14</sup> CPGs appear to be activated by lower brain centers, such as the brainstem and the basal

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ganglia, which in turn activate muscles that perform cyclic and repetitive walking movements.<sup>15</sup> The existence of CPGs has been clearly demonstrated in animals, the evidence coming primarily from lower vertebrates.<sup>16</sup> There is also evidence that CPG activity occurs in humans, but activation appears to be a complex process of interplay between higher brain centers and the spinal cord.<sup>16</sup> Even during fetal development, reciprocal kicking motions appear as early as the fourteenth week of gestation, suggesting that the neuronal basis for locomotion is laid down during neurogenesis.<sup>17</sup> The remarkable abilities of newborns to step immediately after birth and infants to exhibit reciprocal kicking provide additional evidence of a functional mechanism for locomotion.<sup>18</sup> Activation of this automatic reciprocal mechanism is believed to play an important role in the stimulation of ambulation using BWSTT after neurological injury, when higher brain centers have been damaged.<sup>16</sup>

Although the results are mixed, BWSTT has shown promising results in the population of adults with stroke.<sup>19–21</sup> In a systematic review of BWSTT literature on patients with stroke, Moseley et al<sup>22</sup> found that there was no significant benefit of treadmill training with or without body support, although there was a trend toward improved overground walking speed and endurance in patients with stroke. There were large intertrial differences in methodology, treatment parameters, and intervention protocols across studies. For example, body weight support ranged from no support to 80% support, frequency ranged from 3 to 5 times per week, training intensity ranged from 5 to 105 minutes per day, and duration ranged from 2 to 10 weeks across the different studies. Despite the trends for increased walking speed and endurance, these large differences between studies limit the conclusions that can be drawn from the review.<sup>19</sup>

In individual studies of BWSTT, significant improvements in walking ability have been identified. When walking ability was measured by the Functional Ambulation Categories,<sup>23</sup> improvements were found in adult patients with stroke who were previously nonambulatory compared with patients who received conventional physical therapy.<sup>20</sup> In addition, significantly improved walking endurance, walking speed, and postural control have been demonstrated in patients after stroke who received BWSTT compared with patients who received gait training without partial weight support. Furthermore, these improvements were shown to transfer from treadmill to overground ambulation.<sup>21</sup> BWSTT at speeds comparable with normal walking velocity can also significantly improve overground walking speed in adult patients after stroke.<sup>24</sup> To address the lack of consistently specified treatment protocols and conflicting results of prior studies, researchers compared combined exercise programs that included BWSTT paired with other interventions; these included upper extremity exercise, lower extremity exercise, and cycling in a randomized and controlled clinical trial with 80 patients who sustained a stroke.<sup>19</sup> Results from this study demonstrated that task-specific training using BWSTT was more effective at increasing walking speed than less task-specific inter-

ventions, such as cycling. Furthermore, no added benefit to the population of adults with stroke was achieved from a lower extremity strengthening program in combination with BWSTT. Improved walking speeds were also maintained at a 6-month follow-up in this population.<sup>19</sup>

The support for intense and task-specific ambulation training and encouraging results from the population of adults with neurological conditions has led to an interest among researchers and clinicians in examining whether BWSTT might be beneficial for children with CP. During the past 10 years, several studies on this topic have been published in peer-reviewed journals.<sup>25–33</sup> The purpose of this present literature review is to determine the effects of partial BWSTT on gait, balance, and endurance in children with CP.

## METHODS

The literature search for BWSTT in children with CP was conducted using the following key words: *adolescent, child, female, gait, male, physical endurance, physical fitness, spastic CP, treadmill training, and walking*. The search was conducted in the following databases: Academic Search Complete, Blackwell Synergy, CINAHL, Cochrane Library, Google Scholar, Health Source: Nursing/Academic, PubMed, ScienceDirect, SCOPUS, and SPORTDiscus. Only research studies published in peer-reviewed journals and published in the English language were included in this review (Table 1).

To examine the strengths and weaknesses of these studies, Sackett's levels of evidence were determined for each of the studies<sup>35</sup> (Table 2). The studies were rated on a 10-point number/letter scale, with 1A being the strongest or most reliable, and 5 being the weakest or least reliable. A total of 10 levels of evidence are recognized in this system, and these range from 1A-C, 2A-C, 3A and B, 4, and 5. One study was rated at level 1B,<sup>32</sup> 6 studies at level 2B,<sup>25,26,30,31,33,34</sup> and 3 studies at level 4.<sup>27–29</sup>

To aid in selection of the best evidence to help guide clinical practice decisions, an additional hierarchical rating system developed by Evans<sup>36</sup> was used, which rates studies from poor to excellent (Table 3). On the basis of the work by Evans,<sup>36</sup> 1 study was rated fair to good,<sup>32</sup> 5 fair,<sup>26,30,31,33,34</sup> and 4 poor or poor to fair.<sup>25,27–29</sup>

## RESULTS

A total of 10 articles on BWSTT in children with CP were found from the years 1997 to 2008 (Table 4). Of these, 1 was a clinical controlled trial,<sup>32</sup> 6 were small cohort studies,<sup>25,26,30,31,33,34</sup> 2 were case reports,<sup>27,28</sup> and 1 was a case study.<sup>29</sup>

### BWSTT in Infants and Toddlers

Two studies with low levels of evidence were found that exclusively studied infants and young toddlers.<sup>25,28</sup> Conducted in 1997 as a small feasibility study, Richards et al<sup>25</sup> described the development and application of intensive locomotion training with partial weight support on a treadmill for 4 children aged 1.7 to 2.3 years. Although limited in scope, this study was the first to demonstrate that BWSTT could be used successfully on infants and toddlers, or

**TABLE 1**  
Description of Searches Conducted on BWSTT in Children with CP

Name of Article	Academic Search		Health Source:							
	Complete	Blackwell Synergy	CINAHL	Cochrane Library	Google Scholar	Nursing/Academic	PubMed	Science Direct	SCOPUS	SPORT Discus
Date of Search	June 18, 2008	June 10, 2008	June 16, 2008	June 17, 2008	June 18, 2008	June 13, 2008	June 18, 2008	June 12, 2008	June 16, 2008	June 13, 2008
Total no. articles found	21	5	48	6	34	7	42	11	54	37
No. articles appropriate for review	3	1	10	1	7	1	8	2	10	5
Begnoche and Pitetti <sup>31</sup>			X		X		X		X	
Bodkin et al <sup>28</sup>	X		X			X	X		X	X
Cherng et al <sup>33</sup>	X		X		X		X		X	X
Day et al <sup>29</sup>			X		X		X		X	
Dodd and Foley	X	X	X	X	X		X		X	
McNevin et al <sup>27</sup>			X				X	X	X	X
Provost et al <sup>30</sup>			X		X		X		X	
Richards et al <sup>25</sup>			X		X				X	
Schindl et al <sup>26</sup>			X		X		X	X	X	X
Unnithan et al <sup>34</sup>			X						X	X

children who had not yet attained independent ambulation.<sup>25</sup> The study by Richards et al was also the first to describe a training program for children that emphasized partial weight support and manual guidance of leg and foot movements on a slowly moving treadmill. In addition, Richards et al reported that parents of these children with CP showed remarkable compliance in attending the lengthy sessions. In all children, Gross Motor Function Measure (GMFM) scores<sup>37</sup> improved from 8% to 23%, with most improvements in dimension E (walking, running, jumping). Gait spatiotemporal parameters were variable with some children increasing and some decreasing velocity, cadence, and stride length. Although improvement was observed in the Supported Walkers Ambulation Performance Scale<sup>38</sup> in all children, and 2 children attained independent gait, the authors did not adjust for maturation of the children during the 4 months of the study.

In a subsequent study by Bodkin et al,<sup>28</sup> the effects of BWSTT were examined during a 23-week period in an 8-month-old infant with an adjusted age of 5.5 months who had suffered a grade III intraventricular hemorrhage. Alberta Infant Motor Scale scores were used as outcome measures and remained below the 5th percentile for the

child's corrected age. Using observational videotape analysis to evaluate step number, step type, and foot position, the infant's gait changed from variable steps to more alternating and single steps in response to the treadmill training. During posttraining assessment of the infant's progress at 3 months, the infant took almost exclusively alternating steps and demonstrated qualitative improvements in stepping and symmetry of gait. After 6 months, the child was ambulatory without asymmetries. Despite a positive long-term outcome for this infant, the study did not control for maturation and therefore must be interpreted as a pilot study for application of this training in the high-risk infant population.

Given that only 2 studies on BWSTT with poor to fair<sup>25</sup> and poor<sup>28</sup> rating have been conducted on this young age group,<sup>25,28</sup> only limited conclusions can be drawn on the efficacy of BWSTT in infants and toddlers. Both studies had lengthy intervention periods of 4 months<sup>25</sup> and 23 weeks,<sup>28</sup> respectively. Although the children in both studies improved in their functional gross motor skills, neither study was controlled for maturation of these children, and

**TABLE 2**  
Levels of Evidence by Sackett<sup>35</sup>

Level of Evidence	Description
1A	Systematic review of Randomized Controlled Trials (RCT)
1B	RCTs with narrow confidence intervals
1C	All or none case series
2A	Systematic review cohort studies
2B	Cohort study/low quality RCT
2C	Outcomes research
3A	Systematic review of case controlled studies
3B	Case-controlled study
4	Case series, poor cohort case controlled
5	Expert opinion

**TABLE 3**  
Levels of Evidence by Evans<sup>36</sup>

Level of Evidence	Description
Excellent	Strongest scientific base for clinical practice; least risk of error; optimal for the development of practice guidelines
Good	Sound basis for clinical practice; low risk of error; highlights areas where replication of research is needed
Fair	Varying degrees of risk of error; no strong evidence for clinical practice; studies represent initial exploration of interventions and identifies in prioritizing future research
Poor	Serious risk of error or bias; poor basis for clinical practice; can help determine research priorities, but greater risk it may be wrong

**TABLE 4**  
Description and Outcomes of Studies Evaluating BWSTT in Children with CP

Study	Type of Study	Sackett <sup>35</sup> Level of Evidence	Evans <sup>36</sup> Level of Evidence	Frequency, Duration, Conditions	Patient Population	Important Outcome Measures (Pretest-Posttest Design)	Important Results
Begnoche and Pitetti <sup>31</sup>	Small cohort study (pilot study)	2B	Fair	3–4 times/wk for 4 wk, 15–35 min/session, in addition to traditional physical therapy intervention, with as much weight as possible taken by children	1 male, 4 female, aged 2.3 to 9.7 y, diagnosed with spastic quadriplegia and spastic diplegia, 2 Gross Motor Function Classification System (2 GMFCS level I, 1 GMFCS level III, 2 GMFCS level IV)	All 5 dimensions of GMFM.* Functional Skills and Caregiver Domains of the Pediatric Disability Inventory (PEDI). Timed 10-m walk test. Pedographs.	No significant changes in GMFM scores, but positive changes for each of the 5 dimensions. Four of the 5 children had total percent score improvements. No significant changes in the PEDI scores, but 3 showed improvement in percentage of scores. All increased ambulation speed in the timed 10-m walk test, but the results were not statistically significant
Bodkin et al <sup>28</sup>	Case report	4	Poor	4 times/wk for 3 days/wk, for 12 wk, for 2 intervals of 2 min 20 sec with 2-min break between intervals, followed by 11 wk of same protocol carried out by infant's mother at home, in addition to traditional physical therapy intervention, weight support determined by clinical judgment	1 male, age 5 mo, diagnosed with s/p prematurity and grade III intraventricular hemorrhage (IVH). (GMFCS level not specified.)	Alberta Infant Motor Scale (AIMS). Observational videotape analysis (step number, step type, foot position).	AIMS scores remained below 5th percentile for infant's corrected age. Videotape analysis revealed observed changes from variable steps to more alternating and single steps. During posttraining assessment, infant took almost exclusively alternating steps. Child was ambulatory without asymmetries at 3 mo post-test
Cherng et al <sup>33</sup>	Small cohort study	2B	Fair	2–3 times/wk for 36 wk, 20 min/session with randomized, alternating treatment design of traditional intervention (A) and BWSTT(B) intervention of 12 wk each (AAB and ABA), weight support determined by clinical judgment	6 male, 2 female aged 3.5 to 6.3 y, diagnosed with spastic cerebral palsy. (2 GMFCS level II, 6 GMFCS level III.)	Muscle tone. Selective motor control. GMFM. Temporal-distance gait parameters with GAITRite.	No effect on muscle tone. No effect on selective motor control. Significant improvements in dimensions D and E. Significant improvements in stride length. No significant change in gait speed or cadence
Day et al <sup>29</sup>	Case study	4	Poor	3 times/wk for 10 wk, followed by 2 times/wk for 11 wk for 19–25 min/session, in addition to traditional physical therapy intervention, 55% average weight support	1 male, age 9 y, diagnosed with spastic tetraplegic cerebral palsy. (GMFCS level not specified.)	GMFM. PEDI	GMFM scores improved in all dimensions, with ranges from 3%–12%. PEDI scores improved in all domains, but did not exceed standard of error (SEM) for the scaled scores. Parents reported subjective improvements in caretaking

(Continued)

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(Continued)

Study	Type of Study	Sackett <sup>35</sup> Level of Evidence	Evans <sup>36</sup> Level of Evidence	Frequency, Duration, Conditions	Patient Population	Important Outcome Measures (Pretest-Posttest Design)	Important Results
Dodd and Foley <sup>32</sup>	Clinical controlled trial (matched pairs)	1B	Fair to good	2 times/wk for 6 wk, maximum of 30 min/session, in addition to traditional physical therapy intervention, weight support determined by clinical judgment	10 male, 4 female, ages 5.5–14.7 y, diagnosed with moderate to severe athetoid, spastic quadriplegia and spastic diplegia. 7 in each intervention and control group, matched for sex, age and type of CP. (10 GMFCS level IV, 4 GMFCS level III.)	10-min walk test. Timed 10-m walk test	No significant improvement in 10-m walk test. Six of the 7 in treatment group improved self-selected walking speed over 10 m. Mean improvement for walking speed was 68% with a large effect size. No significant improvement in 10-min walk test. Five of the 7 improved their walking distance in the 10-min walk test
McNevin et al <sup>27</sup>	Case report	4	Poor	2 sessions, 1 wk apart, Treadmill training without support and with 30% support for three 3-min intervals with 3-min rest periods, 11 kg weight support	1 female, age 17 y, diagnosed with spastic cerebral palsy. (GMFCS level not specified.)	Heart rate (HR), blood pressure (BP), walking speed on treadmill	BWSTT condition yielded statistically significant lower HR, BP and RPE scores than walking without partial support on the treadmill. Recovery of HR and BP during the rest periods showed no difference between the two conditions. Walking speed was higher during BWSTT with increased stumbling at faster speeds vs unsupported treadmill training at self-selected speeds
Provost et al <sup>30</sup>	Small cohort study	2B	Fair	6 times/wk for 2 wk, 30 min/session, 2×/day, no additional physical therapy during 2-wk intervention mentioned, 30% weight support initially, reduced to 0% over time	4 male, 2 female children, ages 6–14 y, diagnosed with hemiplegia and asymmetrical spastic diplegia. (All children GMFCS level I.)	6-min walk test Energy Expenditure Index (EEI). <sup>†</sup> Timed 10-m walk test GMFM-Dimension E Single leg balance test	No significant changes in the 6-min walk test. Significant differences were found in EEI and 10-m walk velocity test. No significant changes in GMFM scores and single leg balance test. Half of the children showed a decline in 6-min walk test and single leg balance test, where other children made large changes in those tests
Richards et al <sup>25</sup>	Small cohort study (feasibility study)	2B	Poor to fair	3 times/wk for 4 mo, 15–20 min/session as tolerated, in addition to traditional physical therapy intervention, 0%–40% weight support depending on child's ability	1 male, 3 females, ages 1.7 to 2.3 y, diagnosed with spastic diplegia, quadriplegia and hemiplegia, all nonambulatory, two children able to step with support, 2 children unable to initiate stepping movements. (GMFCS level not specified.)	GMFM. Observational gait spatiotemporal parameters with gait videography. Supported Walkers Ambulation Performance Scale (SWAPS). <sup>‡</sup> Gait analysis in Gait Laboratory	GMFM scores improved in all children with most improvements in dimension E. Gait spatiotemporal parameters were variable with some children improving and some decreasing velocity, cadence and stride length. SWAPS showed improvements in all children and 2 children attained independent gait

(Continued)

**TABLE 4**  
(Continued)

Study	Type of Study	Sackett <sup>35</sup> Level of Evidence	Evans <sup>36</sup> Level of Evidence	Frequency, Duration, Conditions	Patient Population	Important Outcome Measures (Pretest-Posttest Design)	Important Results
Schindl et al <sup>26</sup>	Small cohort study	2B	Fair	3 times/wk for 3 mo. 20–25 min/session, in addition to traditional physical therapy intervention, 0%–40% weight support to prevent knee buckling	4 male, 6 female children, aged 6–18 y, diagnosed with spastic diplegia, spastic tetraplegia and spastic tetraplegia with additional ataxia; Children were divided into group A (6 children) (nonambulatory, FAC 0) and group B (4 children) (ambulatory with varying degrees of assist, FAC 2, 3, 4) (GMFCS level not specified.)	Functional Ambulation Categories (FAC). <sup>8</sup> GMFM—Dimension D and E	Significant changes in FAC. One child in non-ambulatory group A improved by 3 levels, 2 children improved by one level and 3 children did not improve. Significant improvements in GMFM. Most improvements in GMFM Dimensions D and E in ambulatory group
Unnithan et al <sup>34</sup>	Small cohort study	2B	Fair	Three 4-min treadmill walks on 3 separate days, using 3 different conditions: harness without weight support, harness with partial weight support, harness with partial weight support plus lateral stabilization with bungee cords	2 female and 3 male children ages 12.4 ± 3.6 y, diagnosed with spastic diplegic cerebral palsy. (All children GMFCS III.)	Metabolic measures (absolute oxygen consumption, HR, ventilation, oxygen cost per stride) via computerized oxygen uptake system	Significant decrease in oxygen cost of walking and ventilation during BWSTT compared with no weight support or weight support with additional lateral support

\*Gross motor Function Measure (GMFM)<sup>37</sup> has 5 dimensions (A: lying and rolling; B: sitting; C: crawling and kneeling; D: standing; E: walking, running, and jumping).

†Energy Expenditure Index (EEI)<sup>39</sup> is calculated by subtracting resting heart rate (HR)(beats/min) from HR during ambulation (beats/min) and dividing it by ambulation velocity (m/min).

#Supported Walkers Ambulation Performance Scale (SWAPS)<sup>38</sup> has 4 dimensions for nonindependent walkers (degree of support; posture; quality of the steps; quantity of the steps).

§Functional Ambulation Categories (FAC)<sup>23</sup> has 5 categories (0: wheelchair used for mobility; 1: maximal assist for walking; 2: continuous or intermittent support for walking; 3: supervision for walking; 4: independent walking, but needs help on stairs and uneven ground; 5: unrestricted walking).

each had only small numbers of subjects, limiting the clinical significance of these studies. Although BWSTT appears to be a safe intervention for infants and toddlers with CP, additional research is needed to determine its effectiveness for infants and toddlers.

### **BWSTT in Preschool and School-Aged Children**

**Effects on Gross Motor Function and Balance.** Five studies examined the effects of BWSTT on gross motor function and balance in preschool and school-aged children, with the latter group having been studied most intensively.<sup>26,29–31,33</sup>

The effectiveness of BWSTT was examined in a case study of a nonambulatory 9-year-old boy.<sup>29</sup> GMFM scores improved in all dimensions, with the largest improvements of 12% occurring in dimension A (lying and rolling), and the smallest improvements of 3% occurring in dimension E. Most notably, this child was able to take up to 60 steps when supported over the treadmill, which he had been unable to do at the start of the study. Likewise, Pediatric Evaluation of Disability Inventory (PEDI) scores improved in all domains, but did not exceed the standard error of measurement for the scaled scores. Parents reported subjective improvements in caretaking, particularly in the ability of this child to bear weight on his legs during assisted transfers, toileting, and dressing. This case study suggests that some improvements in antigravity activities and stepping ability, as well as increased ability to assist during transfers, and weight acceptance through the lower extremities could be made in an older child. However, because the standard error of measurement was not exceeded, this study provides only weak evidence to support the efficacy of BWSTT in this population.

Several other studies with higher levels of evidence examined the effects of BWSTT on gross motor function and balance. Provost et al<sup>30</sup> examined the effects of a short and intense BWSTT program conducted 6 times per week over 2 weeks on 6 children with CP aged 6 to 14 years. No significant changes in functional skill or balance were found in the GMFM and the single leg balance test. Interestingly, some children worsened in their performance on the single leg balance test, whereas other children made large improvements in balance after the 2-week intervention period.

In a 4-week long BWSTT training protocol with intervention given 3 to 4 times per week to 5 children with CP aged 2 to 9 years,<sup>31</sup> no significant changes in the 5 dimensions of the GMFM scores were found. However, positive trends for each of the 5 dimensions were noted, with the largest apparent gains made in GMFM dimension D and dimension E. Although significant changes were not observed in the Caregiver Domain scores of the PEDI across the 5 participants, there were significant improvements in mobility in 1 of the 2 children who ambulated independently at the beginning of the study. In addition, 1 child who required assistance from a walker for ambulation showed significant improvements in the caregiver and self-care domains of the PEDI.

In a study conducted on 8 elementary school-aged children with minimal to moderate disability,<sup>33</sup> an alternating treatment schedule was used over 36 weeks. Traditional physical therapy intervention (condition A) and BWSTT (condition B) were each administered for 12 weeks in 2 groups of 4 children each, who were randomly assigned and matched by GMFCS level. The design of the study followed AAB and ABA schedules. GMFM dimension D and E showed significant improvements after the BWSTT intervention versus the traditional intervention period.

Schindl et al<sup>26</sup> conducted a 3-month long study of 10 children aged 6 to 18 years with BWSTT treatments 3 times per week. The GMFM and the Functional Ambulation Categories<sup>23</sup> showed statistically significant changes and each of the individual children showed improvements in their gait performances with the most gains occurring in the ambulatory group. Specifically, children who were ambulatory with assistance before the beginning of the study improved most in ambulation and high level locomotion skills (e.g., stair climbing) compared with children who were nonambulatory. Children in the non-ambulatory group were able to stand (for an unspecified amount of time) without support after intervention of 3 months on the treadmill, which they had been unable to do before the study. Because the age range of children in this study was 6 to 18 years and the aforementioned motor milestones in ambulatory children are typically met by age 5 years,<sup>37</sup> it is likely that this improvement was due to intervention and not to maturation.

In the 5 studies of preschool and school-aged children, pretest and posttest GMFM scores were used to quantify changes in gross motor function. Two studies<sup>29,31</sup> used PEDI scores in addition to the GMFM scores. Although the majority of individual children showed some degree of improvement in their gross motor skills, significant improvements in the GMFM were only achieved in 2 studies.<sup>26,33</sup> In both of these studies, BWSTT duration was 12 weeks, as opposed to the 3 other studies,<sup>29–31</sup> where BWSTT durations ranged from 3 to 6 weeks. Across all 5 studies, children with initially higher GMFCS levels (I, II, and III) at the start of the study showed positive changes in gross motor function that were primarily related to improved ambulatory skills. Children with lower functional GMFCS levels (IV and V) at the outset of the studies showed reduced dependence on caregivers, improved weight acceptance in the lower extremities during transfers, and improved walking ability when supported in the harness. The results of these studies suggest that BWSTT can have a beneficial effect on gross motor function related to ambulatory skills, especially when longer in duration.

Although balance can be indirectly tested as part of the GMFM and PEDI, it was directly tested using a timed single leg balance test in only 1 study.<sup>30</sup> This study had fair levels of evidence and was conducted on children aged 6 to 13 years. Because some children showed an increase, and

some a decrease in their single leg stance time, the intervention provided in this study yielded no profound effect on balance in this sample of school-aged children.

**Effects on Gait Speed and Endurance.** Gait speed and endurance were examined in 6 studies,<sup>27,30–34</sup> in which the 6- and 10-minute walk test, the timed 10-m walk test, the Energy Expenditure Index, and oxygen cost were used as outcome measures in school-aged children.

In a case study of an ambulatory 17-year-old female with CP, investigators examined whether faster gait speeds with less exertion could be reached during BWSTT versus treadmill walking without support.<sup>27</sup> Heart rate (HR), systolic and diastolic blood pressure scores, and ratings of perceived exertion were recorded in 3-minute intervals across increments of treadmill gait speed, with the treadmill starting at 0.8 km/h followed by a 3-minute rest period. The speed was subsequently increased in increments of 0.32 km/h for 3-minute intervals with 3-minute rest intervals interspersed after each increase. The ambulation/rest cycle was repeated until the subject felt unable to continue. The BWSTT condition yielded significantly lower HR, blood pressure, and ratings of perceived exertion scores than walking without partial support on the treadmill. However, recovery of HR and blood pressure during the rest periods showed no difference between the 2 conditions. Although higher walking speeds were reached during partial unweighting versus unsupported walking on the treadmill, increased stumbling was observed during the faster gait speeds, despite the fact that there was partial weight support.

The effects of BWSTT on oxygen cost were reported in a study of 5 adolescent children who performed 3 sets of 4 minutes of treadmill walking at self-selected walking speed with 3 varying degrees of harness support on 3 separate days.<sup>34</sup> Results showed significant decrease of oxygen use when partial body weight support was provided versus treadmill walking without support.<sup>34</sup> Although the results of this study suggest that BWSTT can be used to provide gait training with reduced physiological strain in adolescents, the long-term efficacy of BWSTT on endurance was not measured in this study.

In a cohort study of 5 children with CP aged 2 to 9 years who were preambulatory, ambulatory with assistive devices, or ambulatory without assistive devices,<sup>31</sup> each child improved his/her speed of ambulation in the timed 10-m walk test. However, taken together, there was no statistically significant effect of BWSTT on walking speed. The wide range of 10% to 76% increase in walking speed in the 10-m walk test was likely due to the large differences in functional level and age in these children with CP.

In a 2-week long study of BWSTT administered 6 times per week on 6 children with CP aged 6 to 14 years,<sup>30</sup> significant improvements were found in the 10-m walk test and the Energy Expenditure Index, whereas no significant changes in walking distance were found in the 6-minute walk test. As has been observed in other studies, large differences among individual children in the 6-minute walk test were likely responsible for the lack of significance.

Although some children excelled in the 6-minute walk test, other children did not change or declined in performance in response to BWSTT, with a trend toward the largest improvements among children with the lowest initial scores. Given the small sample size of this study, a decline in performance in 1 or more children can have an effect on the overall conclusions when examining the children as a group. However, on an individual basis, some children made impressive improvements in walking endurance as measured by the 6-minute walk test.

A 12-week BWSTT training program for 8 children with minimal to moderate disability aged 3.5 to 6.3 years yielded significant improvements in stride length.<sup>33</sup> Although the change in gait speed did not reach significant levels, there was a trend toward increased gait speeds in individual children.

The study with the highest level of evidence and the only clinically controlled trial to date was performed by Dodd and Foley.<sup>32</sup> BWSTT was provided twice weekly for 6 weeks duration for 7 children with CP, while 7 children, matched for sex, age, and ability, did not receive training. All children in this study continued their regularly scheduled physical therapy sessions and engaged in their typical daily activities. Each child had moderate to severe disability that affected the efficiency of ambulation. Although the mean walking speed in the 10-m walk test in the BWSTT group improved from 6.23 to 10.43 m/min compared with the control group, which showed little change from 7.75 to 7.85 m/min, the result was not statistically significant. Despite the lack of significance between the 2 groups, 5 of the 7 children in the BWSTT group showed a strong trend toward improvements in their walking endurance in the 10-minute walk test. In addition, no adverse reactions, such as muscle soreness, pain, increased fatigue, or increased falls were reported. This study confirms the findings of Provost et al<sup>30</sup> who demonstrated that children experiencing significant functional gait limitations may benefit from relatively short BWSTT programs.

The results from these 6 studies show good preliminary evidence as to the efficacy of BWSTT on gait speed and endurance. The most significant improvements were attained during a high-intensity training program of 6 times per week for 2 weeks,<sup>30</sup> while an extended BWSTT protocol of 6 weeks duration with a lower intensity of 2 times per week also showed strong trends toward improved endurance in elementary school children.<sup>32</sup> A BWSTT protocol of 3 to 4 treatments per week for 4 weeks yielded improvements in gait speed in all participants, but overall they were not significant.<sup>31</sup> Even children with moderate to severe disability were able to obtain increased gait speed and endurance across these studies.

## DISCUSSION

Taken together, the 10 studies included in this review indicate that intervention programs with higher intensity (ie, high frequency and extended duration) lead to better outcomes for gait speed, endurance, and improvements in

walking function in school-aged children. Intensive physical therapy intervention programs have been proposed to enhance motor learning in children with CP compared with less intensive programs.<sup>39</sup> Indeed, Ulrich et al<sup>40</sup> showed that intensive BWSTT programs can lead to earlier onset of walking compared with nonintensive BWSTT programs in infants and toddlers with Down syndrome. Furthermore, Ulrich et al demonstrated that treadmill intervention could be provided on a daily basis by parents in the home environment. However, little is known about whether BWSTT administered early and in an intensive fashion can lead to accelerated onset of walking in young children with CP.

In addition to intensity of intervention, percentage of weight support, treadmill speed, and degree of facilitation for leg advancement may also be important for gait speed, endurance, and walking function. Weight support on the treadmill varied widely among the studies reviewed and ranged from 0% to 55%. McNevin et al<sup>27</sup> showed that higher walking speeds could be reached with partial weight support versus unsupported walking on the treadmill, but noted increased stumbling during the faster gait speeds, despite the fact that there was partial weight support. This is consistent with other studies in the pediatric neurological population because it indicates that self-selected over-ground walking speed tends to be the most functional for safety of an individual.<sup>41</sup>

In 4 studies, the percentage of weight support was determined by clinical judgment and based on the posture of the child. Control of excessive knee and hip flexion while still achieving heel strike was described by the majority of authors as a guideline for percentage of weight support provided.<sup>26,31–33</sup> In 3 studies, weight support was determined at a given percentage,<sup>27,30,34</sup> whereas children in 4 studies were progressed to less weight support over the course of the intervention.<sup>25,28,30,31</sup> In the studies reviewed, treadmill speed ranged from 0.2 to over 3 miles/hour. Although BWSTT studies conducted in other patient populations have developed rationales for increasing treadmill speeds based on patient tolerance, changes in vital signs, and quality of gait, no criteria for progression were given in any of the reviewed studies.<sup>19,40</sup> Consequently, criteria for progression of treadmill speed should be more clearly described for children with CP. Percentage of HR increase, perceived exertion, and improvements in step length or height might prove useful factors to begin developing guidelines for this variable. Similarly, facilitation of the legs varied widely among the studies reviewed. Facilitation was not provided in 2 case studies,<sup>27,28</sup> but was provided at the hips, knees, and feet on an “as needed” basis in most studies by 1, 2, and in some cases 3 therapists.<sup>25,26,29–33</sup> As a result, differences in GMFCS levels and ages across studies, as well as a failure to describe the degree of weight support, speed progression, and facilitation in individual children, make it difficult to determine the influence that this variation had on intervention outcomes.

According to motor learning principles, skill acquisition results from reorganization of motor, cognitive, and

perceptual systems in relation to specific tasks and environments.<sup>42</sup> The influence of percentage weight support, treadmill speed, and facilitation for stepping are important when considering these principles. An optimal environment for motor learning requires active participation of the learner in combination with task specificity. Specifically, research on neural plasticity suggests that children with CP benefit most from active exploration to select patterns for optimal function.<sup>43</sup> An important question that comes out of this work is whether children are actively engaged in the motor learning process when they receive weight support and facilitation to advance their legs. In the largest BWSTT study to date in adults after stroke, a treatment protocol was started with 30% to 40% weight reduction and facilitation from up to 3 trainers at the hips, knees, and feet. These practice conditions were reduced over 12 subsequent sessions to no weight support, and no facilitation from trainers.<sup>19</sup> Participants in this study made large gains in relearning the motor skill of walking. However, it is important to distinguish between adults following stroke who are re-learning a previously mastered task and children who are learning the task of walking for the first time. If children need to actively explore motor patterns for optimal gait, reducing the facilitation of leg advancement and weight support in children with CP may provide opportunities for errors. Such errors can lead to self-correction in the protected environment of BWSTT. Given the amount of repetition of the same task during BWSTT, it is possible that accelerated skill acquisition may be achieved during this process. Additionally, “learning with errors” may lead to improved skill transfer to over-ground walking.<sup>44</sup> An added benefit to this approach might be an increased cardiopulmonary training effect due to increased load, and higher bone mineral density due to increased weight bearing.

These concepts of motor learning might also provide an explanation for the limited, and in some children negative, effect on standing balance in children with CP.<sup>30</sup> The decrease in standing balance in some children might be explained by the nature of the BWSTT training itself. Because the harness and handrails provide balance support during the treadmill training, there is no obvious challenge placed on the balance system during BWSTT. Indeed, the treatment is geared toward the functional walking process rather than the process of maintaining postural control during walking. However, because of the lack of studies measuring balance in isolation, there is not enough evidence to date to draw conclusions about the effects of BWSTT on balance.

## Implications for Researchers and Clinicians

Based on the limited number of studies, there is a need for additional research in this area. Researchers should focus on designing clinically controlled or randomized controlled trials with larger sample sizes. Because the number of available subjects is often limited in pediatric practice settings, multicenter trials that use the same outcome measures and standardized treatment protocols offer an excellent opportunity to explore the effects of BWSTT on a

larger scale. An alternative treatment design for BWSTT research is the single subject research design (SSRD). This design has received increased interest from researchers who study children with CP.<sup>45</sup> The SSRD uses a rigorous scientific study design as opposed to a case study, which is inherently descriptive in nature. Recently, a set of guidelines for critical review of SSRDs has been developed. These guidelines should aid researchers and clinicians in developing and reviewing evidence provided by SSRDs.<sup>46</sup>

One difficulty in existing studies was that statistically significant results were often not reached while trends toward improved function were reported. Additional outcome measures that reflect participation on an individual and societal level, as defined by the International Classification of Functioning, Disability and Health (ICF) model<sup>47</sup> and quality of life (QOL) outcome measures, should be included in future studies to better quantify potential benefits of BWSTT in children with CP. Based on existing studies, children with CP appear to respond better to high-intensity BWSTT; however, the optimal training conditions for weight support, treadmill speed, and degree of facilitation of leg advancement of such treatment protocols have not been established for different age groups or different types of CP. Another key question that must be addressed in future research is whether improvements in gross motor function, gait speed, and endurance can be maintained over time. Because there is only weak evidence for efficacy of BWSTT in infants and toddlers with CP, additional studies are needed particularly for young children who reach their motor milestones at an accelerated rate.<sup>37</sup> To determine whether the BWSTT intervention, and not simply maturation, accounts for positive changes in young children with CP, it is essential that investigators control for maturation in future studies. For younger children with CP, SSRDs would offer an alternative research design to larger controlled studies, if a small treadmill and a harness can be made available.

When faced with the question of whether or not to purchase a harness and treadmill for the pediatric CP population in a facility, clinicians must critically examine the evidence. Factors in this decision making process should be the age and diagnosis of the children served in the facility, the goals of the children and their families, and availability of resources for physical therapy intervention several times a week for an extended duration.

## Summary

The past 10 years have produced an important investigation of BWSTT in children with neurologic conditions. Although there is still a relative paucity of research on the effects of BWSTT in this population, there are some encouraging results for children of various ages who are ambulatory and nonambulatory because of CP. Although research on the efficacy of BWSTT in children with CP is still at an early stage, some evidence suggests that it may be a potentially beneficial approach. More evidence exists regarding the efficacy of BWSTT on gait speed, endurance,

and gross motor skills related to ambulation, than on balance in preschool and school-aged children with CP. Because no adverse effects have been reported, BWSTT appears to be a safe intervention method. However, larger, controlled studies, or smaller studies with more rigorous designs, need to be performed to allow pediatric physical therapists to develop higher levels of evidence regarding intervention.

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