Treadmill Training and Overground Gait: Decision Making for a Toddler With Spina Bifida

Victoria A. Moerchen, PT, PhD; Mohammad Habibi, MS; Kelly A. Lynett, BS; Jeffrey D. Konrad, BS; Heather L. Hoefakker, BS

Physical Therapy Program, Department of Human Movement Sciences, College of Health Sciences, University of Wisconsin–Milwaukee (Dr Moerchen, Mr Konrad, and Ms Hoefakker); College of Engineering and Mathematical Sciences, University of Wisconsin–Milwaukee (Mr Habibi); College of Health Sciences, University of Wisconsin–Milwaukee (Ms Lynett).

Background and Purpose: This case report describes a decision-making process that was used to progress a home-based intervention that coupled treadmill and walker stepping for a preambulatory toddler with spina bifida. **Case description:** The toddler in this report had an L4-L5 level lesion, and began this home-based intervention at 18 months of age when she was pulling to stand. **Intervention:** The intervention included parameters for treadmill stepping that prepared this toddler for gait with orthotics and was progressed to overground walking with a walker using a decision-making algorithm based on data obtained from a parent log and coded video. **Outcomes:** This toddler progressed from not stepping at the start of the study to ambulating 150 m with a walker at age 23 months, after 18 weeks of this intervention. **Discussion and conclusion:** The intervention and decision-making process used in this study were family centered and may be applicable to gait intervention with other populations. **(Pediatr Phys Ther 2011;23:53–61)** *Key words: ambulation, case study, decision making, family centered care, gait/physiology, infant, longitudinal studies, lumbar vertebrae, meningomyelocele/physiopathology, meningomyelocele/psychology, meningomyelocele/rehabilitation, motor activity/physiology, muscle contraction/physiology, orthoses, transfer of training, walkers*

Despite the popularity of body weight supported treadmill training as a locomotor intervention for pediatric populations, the development of a protocol for treadmill intervention for preambulatory children with spina bifida (SB) has not been described. Recent research has shown that infants with SB are able to produce steps on a treadmill at ages preceding the onset of trunk control and lower extremity weightbearing.[1] The high variability of residual innervation and the complications of the secondary conditions associated with SB, however, may render development of a standard treadmill protocol unreasonable. In contrast, a clinical decision-making process for the use of a treadmill to support gait acquisition with these children may be more tenable.

Treadmill stepping provides the task-specific practice essential to augmenting neuroplastic change[2,3] that is difficult to accomplish with overground methods. The treadmill differs from traditional approaches to overground gait in that it provides a context for a relatively high level of physical activity that may be critical to the attainment of gait.[4,5] A treadmill protocol to provide this practice for toddlers with Down syndrome (DS) has been reported.[6] With that protocol, a child receives 8 minutes of treadmill training per day, 5 d/wk, in the home with the parent supporting the child on the treadmill while allowing and encouraging the child to take as much weight as possible. Forty minutes of stepping per week during a time when a child is not yet walking overground is a considerable burst in task-specific physical activity (as a function of repeated cycles of stepping) that cannot easily be replicated with overground approaches to providing gait experiences for a child without functional locomotion. The potential utility of this approach for children with SB who are preambulatory is extremely appealing.

0898-5669/110/2301-0053
Pediatric Physical Therapy

Correspondence: Vickie Moerchen, PT, PhD, Department of Human Movement Sciences, College of Health Sciences, University of Wisconsin-Milwaukee, PO Box 413, Milwaukee, WI 53211 (moerchev@uwm.edu).
Grant Support: *This study was partially funded by a grant from the Section on Pediatrics awarded to the first author.*

DOI: 10.1097/PEP.0b013e318208a310

Depending on the degree of paralysis or weakness, the locomotor needs of a child with SB often include orthotic management and preparation for use of an assistive device.[7] To promote translation of stepping skills to functional gait, several researchers have used treadmill training in conjunction with experience walking overground.[8–10] Behrman et al[8] provided a decision-making algorithm for progression of locomotor training that paired experience both on the treadmill and overground for a patient with an incomplete spinal cord injury. We propose that a similar approach for preambulatory children with SB should capitalize on the physical activity possible with a treadmill while translating that to experience stepping overground with the equipment needed by the child. Guidelines for incorporating the treadmill in gait training programs for children with SB need to be inclusive of orthotic management and clinical decisions specific to the individual and the diagnosis.

The purpose of this case report is to describe a decision-making process that was used to progress a home-based gait intervention that coupled treadmill and walker stepping for a toddler with SB who was preambulatory.

DESCRIPTION OF CASE

Toddler Description

The toddler with SB who is described in this case report, began a home-based treadmill intervention program at 18 months of age and continued until 23 months of age. Her lesion level was noted to be L4-L5, with asymmetric innervation evident in observable asymmetry of active control and presence of a distal deformity (left metatarsus adductus). She had undergone spinal closure at 1 day of age, shunt placement at 13 days of age, and serial casting for left metatarsus adductus at 4 months of age. Her medical course was otherwise unremarkable, with only typical childhood illnesses noted. No shunt revisions or orthopedic surgeries were reported. She was the first child born to college-educated parents who held professional level jobs.

At 18 months of age, this toddler was able to bear weight when positioned in standing and was able to pull to stand but had not started to cruise and was described as "very afraid" when placed in a walker. She was selected for this study when she demonstrated an ability to pull to stand, which met the criteria for initiation of the treadmill protocol developed for children with DS[6] who were preambulatory. That protocol served as a starting point for the intervention used in this study. The child was also selected for this study because she was described as "not motivated for upright movement," thus delaying progression of a traditional gait program in her early intervention program. She was known to us from a previous study, and even at younger ages she preferred not to move. A final selection criterion, critical to this intervention, was that her parents were able to commit to a program of treadmill stepping a minimum of 5 days a week across the duration of the intervention.

Assessments of alignment, range of motion, muscle function, and mobility were performed by a physical therapist before, during, and at the conclusion of this intervention. Alignment and range of motion were unremarkable except for a 3° to 5° limitation to full plantar flexion on the right and a great toe flexion contracture, also on the right (not measured) that was present across the intervention. Muscle function at 18 and 23 months of age is presented in Table 1. From the start of this study, this toddler had solid ankle-foot orthoses that were prescribed to promote stance and gait activity.

Developmental data reported by the parents included gross motor development at the 16th percentile at 3 months and 9 months of age (Bayley-III).[11] This toddler was 18 months old at the start of this study, and her gross

TABLE 1

Muscle Test Results at Beginning and End of the Home-Based Treadmill Intervention for the Toddler With a Lesion Level of L4-L5

	18 months (pretreadmill)		23 months (posttreadmill)	
Muscle	Right	Left	Right	Left
Hip flexors (L1,**2**,**3**,4)	Present (3*)	Present (3*)	Present (3*)	Present (3*)
Hip adductors (**L2**,**3**,4)	Present (3*)	Present (3*)	Present (3*)	Present (3*)
Knee extensors (Quad) (**L2**,**3**,**4**)	Present (3*)	Present (3*)	Present (3*)	Present (3*)
Tibialis anterior (**L4**,**L5**,S1)	Present (3*)	Absent	Present (3*)	Weak
Gluteus medius (**L4**,**L5**,**S1**)	Weak	Absent	Present (3)	Weak
Peroneus long/Brev (**L4**,**L5**,S1)	Present (3)	Absent	Present (3)	Absent
Medial hamstrings (L4,**L5**,**S1**,2)	Present (3)	Weak	Present (3)	Weak
Tibialis posterior (**L5**,**S1**)	Absent	Absent	Absent	Absent
Flexor hallicus longus (**L5**,**S1**,2)	Present (C)	Absent	Present (C)	Absent
Gastroc-Soleus (L5,**S1**,**2**)	Absent	Absent	Weak	Absent
Lateral hamstrings (L5,**S1**,**2**,3)	Not testable/obs	Not testable/obs	Not testable/obs	Not testable/obs
Gluteus maximus (**L5**,**S1**,**S2**)	Not testable/obs	Absent	Weak	Absent

Given the age of this child, muscle function was scored using absent, weak, and present. "3" indicates that the segment was moved against gravity; "*" indicates that the muscle exceeds fair grade as observed; and "C" indicates contracture. As noted in this chart, some muscle function was not testable with this toddler nor was it adequately observed during play. Bold denotes a major source of innervation. Muscle innervations taken with permission from Kendall et al.[29]

motor development was at the 0.1 percentile (Bayley-III),[11] limited by lack of leg control and delayed locomotor skill acquisition.

Outcome Measures

The outcome measures used in this case included (1) overground gait distance quantified measured using the Functional Mobility Scale[12] and (2) functional use of gait quantified using the Pediatric Evaluation of Disability Inventory.[13]

DESCRIPTION OF INTERVENTION

This intervention coupled treadmill training with progressive use of a walker (TM + W) to assist this toddler with SB in achieving functional gait. Decision making for this process is summarized in Figures 1 and 2. Figure 1 provides a broad overview of the process of updating the intervention relative to the goal of functional use of walker-assisted gait. Figure 2 provides more specific details of the process of setting initial conditions and progression within these conditions, for the treadmill and walker components of the home program.

The toddler continued to receive weekly early intervention physical therapy (PT) across the duration of this study. Consistent with the parallel implementation of treadmill training for toddlers with DS,[6] there was no attempt to direct or shape these services during the implementation of this home-based TM + W intervention. The clinician providing PT reported that this toddler's direct PT during the period of this study was 45 minutes per week, and focused on trunk stability and tolerance to standing when the toddler was 18 to 20 months of age, and focused on gait with a walker and transitions in/out and up/down from a walker when the toddler was 20 to 23 months old. This study was approved by the institutional review board at the University of Wisconsin-Milwaukee, and the toddler's parents signed an informed consent before beginning this home-based training.

Treadmill Training

During the treadmill training we used a custom-designed infant treadmill that was placed in the family home. The toddler was manually supported over the treadmill by the parents, as described for the established protocol for toddlers with DS.[6] The conditions of the treadmill training for gait acquisition (TM_{ga}), specifically treadmill belt speed, duration of stepping, and neuromechanical factors (sensation, constraint, and load), were individualized and updated to progress the treadmill portion of the intervention.

Overground Gait

Walker assisted gait (W) is the expected overground gait outcome for a child with a low lumbar lesion.[14–17] Overground gait in this intervention was progressed based on the distance the toddler was able to ambulate (see Figure 2). The clinical decision-making process was guided by a longer term ambulation goal set by the family.

Initiating and Progressing the Intervention

The intervention was progressed when the parents of the toddler reported one of the following: the stepping had become "easy," the duration of stepping had plateaued, or

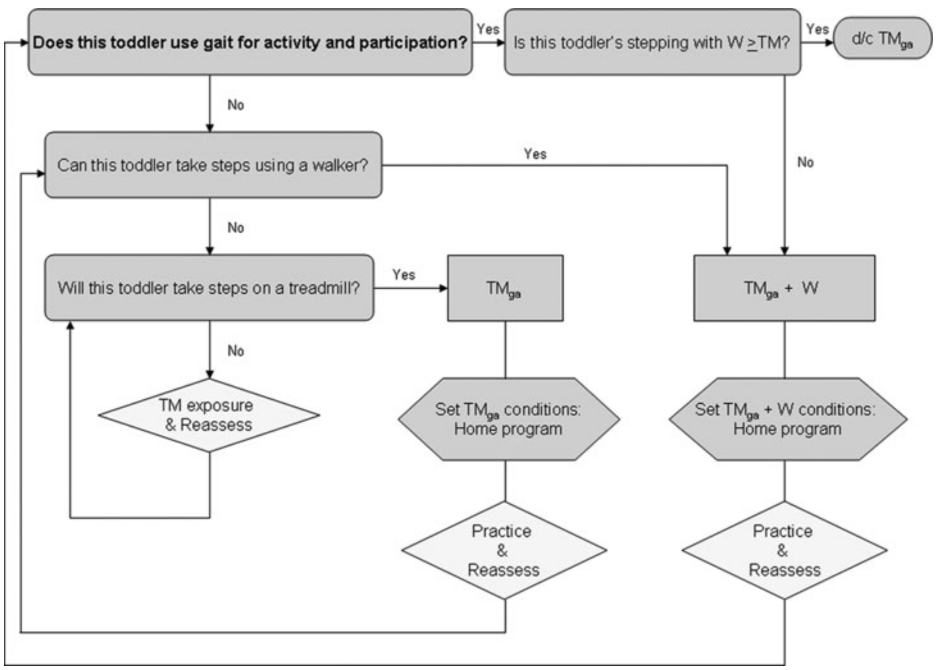

Fig. 1. Decision-making algorithm for a coupled treadmill and walker intervention for gait acquisition in a toddler with spina bifida. Abbreviations: d/c, discontinue; TMga, treadmill training for gait acquisition; W, walker.

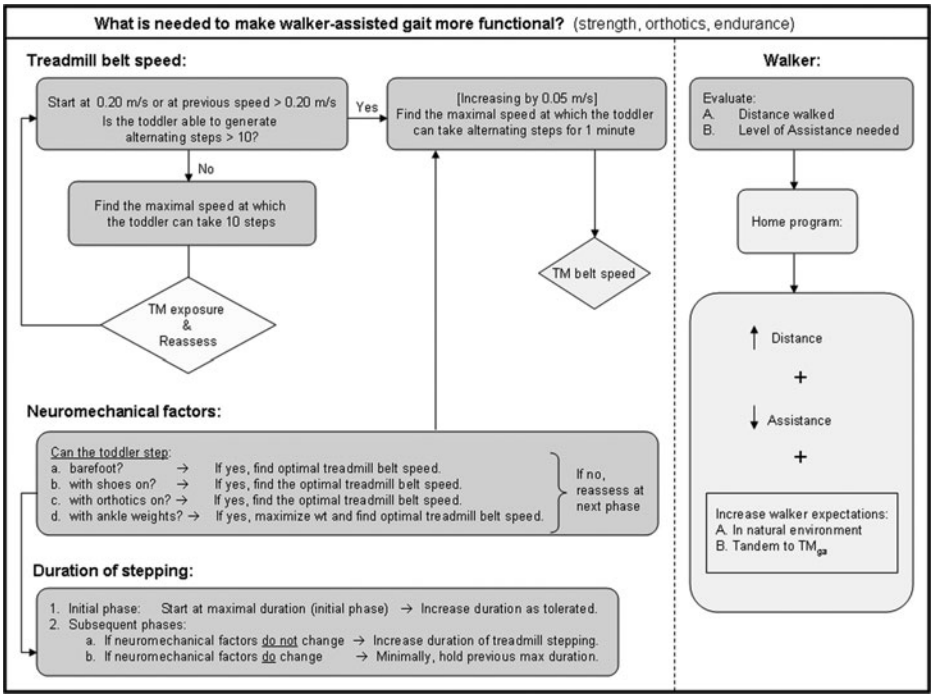

Fig. 2. Decision-making algorithm for selecting and progressing components of a coupled treadmill and walker intervention for gait acquisition in a toddler with spina bifida. Abbreviation: TMga, treadmill training for gait acquisition.

they had a concern related to either the treadmill stepping or walker stepping. At each progression point, the following parameters were considered using the algorithm described in Figure 2.

Duration of stepping. Because this intervention was a home program conducted by the toddler's parents, a parent log of daily-stepping duration and conditions, and weekly home video of stepping, allowed tracking of the home program.[6] Each home video sample (lateral view) recorded an entire daily treadmill period for the toddler. The parent log and home video data were used to determine duration of stepping (mean, range, total per session, and total per week).

Treadmill belt speed. The process for determining the initial treadmill belt speed and for updating this speed is illustrated in Figure 2. An initial speed of 0.20 m/s was selected on the basis of previous studies that have documented effective treadmill belt speeds for infants with SB.[1] The intervention was progressed by observing the toddler's stepping response at treadmill speeds that increased by 0.05m/s. The highest speed at which the toddler could produce alternating steps continuously for 60 seconds was determined to be optimal and was assessed per neuromechanical factors.

Neuromechanical factors. Neuromechanical factors such as sensory input, mechanical constraint, and load were manipulated in this intervention to assist this toddler's acquisition of gait. The gait program of a toddler with SB with a lower lumber lesion is expected to include orthotics for mechanical control.[7,18] An orthosis introduces a constraint to range of motion, a physical load (orthotic + shoe), and some friction as a function of the sole of the shoe worn over the orthosis. Further, the orthosis reduces the degrees of freedom available for self-selected motor control, and it alters the sensory input that might be available to the toddler (dependent on residual sensory function) and that may be useful to acquiring ambulation. As a result each of these neuromechanical factors was given a place in the design and progression of this toddler's TM_{ga} + W intervention. The use of ankle weights was included because an externally applied load to the limb of the toddler provides a mechanism for strengthening. The neuromechanical factors used for this gait acquisition intervention were barefoot, shoes, orthotics (plus shoes), and weights. The response to these factors was assessed at each clinical progression point, as portrayed in Figure 2.

Additional data. Electromyographic (EMG) activity of the quadriceps, hamstrings, tibialis anterior, and gastrocsoleus were recorded prior to initiating the intervention and after 3 weeks of treadmill stepping. These data were deemed necessary to reinforce the clinically applicable observational approach to decision making and to support the decision to emphasize barefoot treadmill training early in the intervention.

EMG signals were captured at 60 Hz, using preamplified bipolar 2.0 cm × 3.0 cm electrodes (Etrode, Fort Lauderdale, FL) for each muscle; the reference electrode was placed on the sacrum below the toddler's surgical scar. The band-pass filter and sampling rates were 10 to 500 Hz and 1200 Hz, respectively.[19] Each time EMG data were collected, six 30-second trials were conducted—3 trials with treadmill stepping while barefoot and 3 trials with treadmill stepping while wearing orthotics and shoes.

Data Reduction

Step rates. All video data were behavior coded by frame for step type and frequency, following the methodology of Thelen and Ulrich.[20] Dependent variables included total steps, total alternating steps, length of alternating sequences, and rate of stepping (number of steps/duration of stepping).

Duration of stepping. Parent logs were summarized for total time spent stepping across conditions and across the intervention phases.

Muscle activity. Raw EMG signals were band-pass filtered using a Butterworth digital filter, order 6, with the cutoff frequency of 40 to 250 Hz to eliminate the low frequencies (motion artifact) and high frequencies (signal smoothing).[21] After band-pass filtering, the data were *z* scored, using MatLab 7.1 (The MathWorks, Inc, MA).

The onset of the EMG activity is a marker for the onset of active control and is, therefore, one of the most common parameters evaluated from EMG records.[22] Approximated Generalized Likelihood Ratio (AGLR)[23–25] was employed as the method for computer-based detection of muscle activity for this study. The AGLR algorithm slides a window of a fixed size (manually set at 50 samples for this study), along the data and estimates the variance. Muscle activity is determined to be "on" whenever the AGLR test function exceeds the threshold (mean of the signal). After detecting all the "on" and "off" points in the EMG time series per muscle per trial, total "on" time was calculated across trials to provide a measure of each muscle's activity during stepping by this toddler for whom some degree of incomplete or absent innervation was expected.

RESULTS AND OUTCOMES

Clinical decision making occurred at the start of the intervention to establish the initial conditions for the intervention, and again at each point when the parent report suggested that a change in the intervention might be needed. Data supporting initial conditions and intervention progression are outlined below. A goal of ambulating 50 m with the walker was set by this toddler's parents and anchored the decision making related to a family-centered definition of "gait acquisition." An overview of this toddler's program and outcomes are summarized in Figure 3.

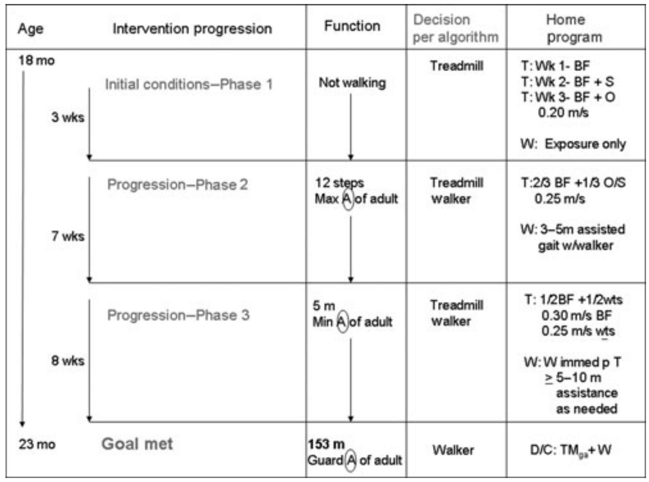

Fig. 3. Summary of intervention program and outcomes for the toddler in this study.The progression of the intervention for this toddler can be followed by making a "z" through the cells, starting with the summary of function at the initial phase and then progressing horizontally to the corresponding home program summary, then progressing diagonally downward to the left to the next summary of function and then again right to the updated home program, and continuing this through the phases of intervention to the point where the coupled treadmill and walker intervention was discontinued.

Initial Conditions—Phase 1

To establish initial conditions for this intervention, the toddler's overground gait with a walker was assessed. She was unable to take steps using the walker, even with maximal assistance. In contrast, she was able to produce continuously alternating steps when held on a treadmill.

Determining the TM_{ga} conditions for phase 1. A treadmill belt speed of 0.20 m/s was determined to be optimal following the algorithm of Figure 2. Neuromechanical factors were selected resulting in an emphasis on barefoot stepping. Because this toddler was not motivated for overground gait, an additional emphasis of this initial home program was on preparing her for overground stepping, which would include the use of orthotics. Progressive exposure to treadmill stepping while wearing shoes and orthotics was implemented in a step-wise manner, with a plan to reassess her response in 3 weeks.

Phase 1 home program. The initial home program consisted of barefoot stepping during week 1, introduction of shoes during week 2, and introduction of orthotics during week 3 (orthotics = orthotics + shoes). Stepping in each condition was at treadmill belt speeds of 0.20 m/s. To facilitate the child's readiness for progression to the TM_{ga} + W intervention, play while standing in a walker was encouraged at home, during these initial 3 weeks of the TM_{ga} intervention.

Progression of Intervention—Phase 2

After 3 weeks of treadmill stepping, gait status with a walker was reassessed. The child was able to take 12 steps. Thus, according to our algorithm, the intervention during phase 2 was progressed to TM_{ga}+ W.

Examining data from phase 1. The parent log revealed that the home program had been implemented as planned, and that the majority of the initial treadmill stepping had been done with the toddler barefoot, with some experience stepping with shoes and orthotics (Figure 4). Step rates in shoes and orthotics were similar, but step rates while barefoot were greater (Figure 5). This might be expected from greater experience stepping barefoot than when wearing shoes or orthotics during phase 1 of the intervention. Increased step rates while barefoot as compared to step rates when wearing a shoe or orthotic might

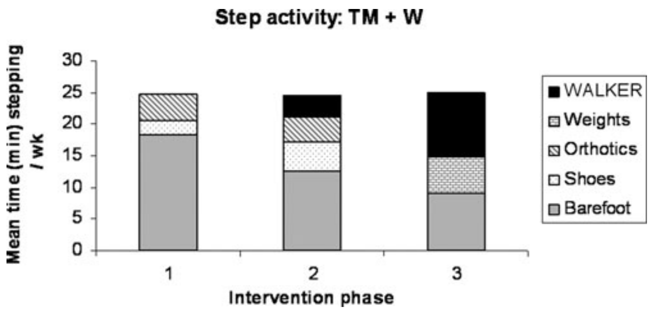

Fig. 4. Total time (minutes) spent stepping per week across intervention conditions during each phase of the coupled treadmill (TM) and walker (W) intervention, based on data from the parent log.

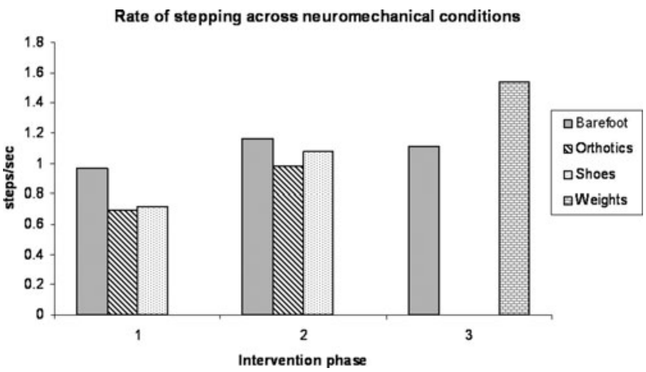

Fig. 5. Rates of treadmill stepping (steps/sec) across treadmill conditions and intervention phases.

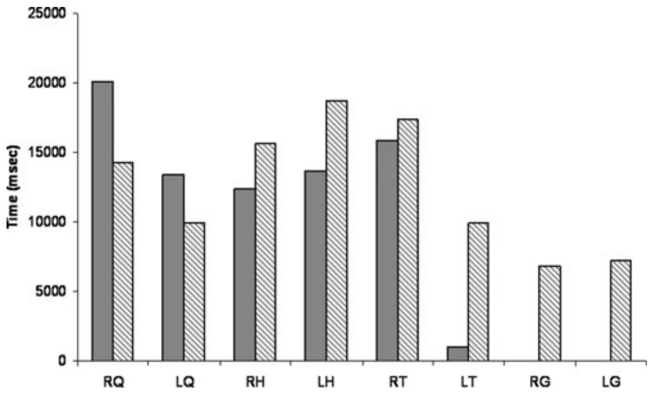

Fig. 6. Total "on" time per muscle during barefoot stepping prior to the start of phase 1 (solid bars) and after 3 weeks of experience with stepping (patterned bars). There was no "on" time detected for gastrocsoleus at the start of the intervention. Abbreviations: G, gastrocsoleus; H, hamstring; L, left; Q, quadricep; R, right; T, tibialis anterior.

also reflect the additional mechanical load associated with the latter items.

Check-point: Examining muscle activity during barefoot stepping. Comparison of muscle "on" times during barefoot stepping initially and after 3 weeks of experience with stepping (pre-phase 1 and post-phase 1) showed that total muscle "on" time increased, except for the quadriceps, bilaterally (Figure 6). It is possible that the experience of increased leg activity that occurred with treadmill stepping changed the recruitment or firing rate of muscles with at least partial innervation. The increase in activity after 3 weeks of treadmill training reinforced our observations (video and parent log) that stepping barefoot was an effective strategy for increasing leg activity in this toddler. We propose that the reduction of quadriceps "on" time may have reflected improvements in the control of stepping, as quadriceps onset based on visual inspection of the signal was more periodic after 3 weeks of treadmill training. [Note: This toddler did not tolerate EMG recording well, so the use of EMG was discontinued after this point.]

Determining TM_{ga} conditions for phase 2. Increasing the speed of the treadmill belt changes the organizational demands on the neuromotor system. An increase to 0.25 m/s was tolerated by the toddler at this point, as evidenced by no decrease in length of sequences of alternating steps; but the length of sequences decreased when treadmill speed was increased to 0.30 m/s. Given the reduced rates of stepping with shoes and orthotics, a decision was made to continue to emphasize barefoot stepping, while on alternate days spending about 1/3 of the treadmill time stepping with orthotics or shoes.

Determining W conditions for phase 2. Phase 2 of the intervention was the first point at which $TM_{ga} + W$ occurred, as the toddler could now take 12 steps with assistance. Short distances (3 to 5 feet) of assisted stepping with a walker were added to the stepping program. We suggested that the parents begin this at times during the day when the toddler was rested, and then as distance and tolerance increased, include stepping with the walker subsequent to the treadmill stepping.

Phase 2 home program. The home program for phase 2 thus increased the treadmill belt speed to 0.25 m/s, but did not change the neuromechanical factors used with the treadmill stepping. Additionally, stepping with a walker became part of the overall stepping home program, with a plan to couple the 2 stepping contexts ($TM_{ga} + W$) in this phase as the toddler's daily use of the walker progressed.

Progression of Intervention—Phase 3

Overground gait was reassessed after 7 weeks of treadmill training during phase 2 when treadmill training was paired with daily experience using the walker for short distances. At this point (after 10 weeks of intervention, across phases 1 and 2), the toddler was able to ambulate 5 m with minimal assistance from an adult. The parent goal of the toddler ambulating 50 m and the overall goal of gait being used for activity and participation were not met. According to our algorithm, phase 3 required further progression of $TM_{ga} + W$.

Examining data from phase 2. The parent log recorded that the amount of time spent stepping barefoot was 4 times the amount of time spent stepping with a walker, and the experience stepping with the walker was similar to the mean exposure to treadmill stepping in shoes and orthotics (Figure 4). The parents reported concern related to their observations of internal rotation of their daughter's lower leg (L>R) during stepping when wearing orthotics, both on the treadmill and with the walker. We replicated this observation when we reassessed treadmill belt speeds during stepping with orthotics. Although walker assisted ambulation distances had increased, alignment during stepping in both the treadmill and walker contexts was clearly a concern.

Several hypotheses were generated to account for these observations and were considered in decision making for ongoing treadmill intervention. First, muscle imbalances may have accounted for emergent swing with internal rotation, evident as the toddler's ability to take steps increased. Second, the mechanical constraint on ankle motion secondary to use of the orthotics, resulted in this compensation from terminal stance through swing. Third, the mass of the orthotic was too great for her strength.

We elected to address the second and third hypotheses by examining barefoot treadmill stepping with ankle weights equal to the mass of the orthotics (plus shoes). Our rationale was that this would replicate the mechanical load of the orthotics, without imposing the mechanical constraints to ankle range of motion, allowing us to determine what might be contributing to these alignment concerns and how best to address this in the $TM_{ga} + W$ intervention. We found that stepping with weights equal to the mass of the orthotics did not result in the observed internal rotation of the distal segment and the toddler's rate of stepping with weights was not less than that observed previously for orthotic stepping.

Determining TM_{ga} conditions for phase 3. Treadmill belt speed for barefoot stepping was increased to 0.30 m/s. Neuromechanical factors were adjusted to (*a*) eliminate stepping with orthotics and shoes and (*b*) add treadmill stepping with weights equal to the weight of the orthotics (plus shoes). This load was selected to address third hypothesis (with regard to the observed alignment challenges) and was relevant to expectations that this child would eventually walk overground wearing orthotics as her functional ability progressed. Treadmill belt speed for stepping with weights was 0.25 m/s. Time spent stepping in barefoot and with weights was targeted to be equal across the treadmill period of the intervention. Given the change in neuromechanical factors, the total duration of treadmill stepping was to either be held constant (25 minutes) or increased.

Determining W conditions for phase 3. A decision was made to extend the stepping period by immediately appending walker stepping to the conclusion of treadmill stepping. Total distance for overground stepping was to start with 5 m and increase as tolerated and as possible within and around the family home. Caregiver assistance with overground gait was to be decreased, so that increasingly motivation for and control of overground stepping would be initiated by the toddler. At this time walker stepping in shoes only was preferred by the parents.

Phase 3 home program. In phase 3 of the home program treadmill stepping with orthotics and shoes was discontinued, and stepping with weights equal to the weight of the orthotics (plus shoes) was added. Half of the treadmill stepping was done barefoot and the other half with weights. The treadmill belt speed was established at 0.25 m/s for the weighted condition and was increased to 0.30 m/s for the barefoot condition. Coupling treadmill exposure with overground stepping paired a context that supported rhythmic activity of the legs with use of the same muscle activation patterns to move the mass of the body forward, thus promoting immediate translation of stepping skills to overground gait. The total duration of $TM_{ga} + W$ was anticipated to increase beyond 25 minutes.

Goal Met: Discontinuing the $TM_{ga} + W$ intervention

After 8 weeks of treadmill intervention during phase 3 (total treadmill experience was now 18 weeks), this toddler was reported to be using gait for functional activities. When maximal gait distance overground was assessed, the total distance of 153 m exceeded the 50 m goal set by her parents. Further, her parents felt that her physical activity during stepping was greater now overground than on the treadmill. Following our algorithm, the $TM_{ga} + W$ intervention was discontinued.

Examining data from phase 3. Review of the parent log and home video tapes provided a picture of the toddler's response to phase 3 of this coupled intervention. Whereas step rates for stepping barefoot seemed to plateau, the rate of stepping with weights exceeded that of barefoot stepping (Figure 5). The parents reported that after 1 week of treadmill stepping with weights, the toddler's tolerance of using the walker and the distance she would walk with the walker began to increase.

Outcome Measures

Table 2 summarizes functional mobility outcomes across the 18 weeks of the study. Functional mobility increased and caregiver assistance decreased, consistent with this toddler's acquisition of gait. Although she could walk a distance of 153 m with her walker and much adult encouragement, she preferred crawling for distances greater than 50 m, unless an adult encouraged gait. Fifty meters was still considered functional for activity and participation at home and at day care. At the conclusion of this intervention, this toddler was walking with her walker without use of her ankle-foot orthoses.

DISCUSSION

This case report describes a decision-making process to progress an intervention that coupled treadmill stepping with walker-assisted gait for a toddler with SB (L4-L5). This intervention was conducted in the home by the parents a minimum of 5 days per week. At the start of this

TABLE 2

Functional Mobility at the Start and Conclusion of the Coupled Treadmill and Walker Intervention

Functional assessments	18 months	23 months
PEDI **Mobility Domain**		
F (Indoor, method, 3pts)	1	2
G (Indoor, distance, 5 pts)	1	3
H (Indoor, objects, 5 pts)	2	4
I (Outdoor, method, 2pts)	0	1
J (Outdoor, distance, 5 pts)	0	4
K (Outdoor, surfaces, 5 pts)	0	3
Caregiver asst & modifications, Mobility Domain		
E (Indoor locomotion)	0	4/R
F (Outdoor locomotion)	0	4/R
FMS		
Scored performance	0,0,0	2,2,0
Child-selected mobility	C,N,N	W,C/2,N

For the FMS, "C" denotes that the child crawls for mobility at home; "W" denotes that the child uses a walker for mobility; and "N" denotes that the toddler does not complete the distance. Where C/2 is indicated, the toddler preferred to crawl, but could be encouraged to use her walker.

Abbreviation: FMS, Functional Mobility Scale; PEDI, quantified using the Pediatric Evaluation of Disability Inventory; pts, points possible.

intervention, the toddler was just pulling to stand and was afraid to stand in or move with a walker. As experience stepping increased, so did this toddler's tolerance of upright activity and her willingness to use a walker. Across the 18-week period of the intervention, she progressed to an ability to use the walker for activity and participation, surpassing a 50-m ambulation goal set by her parents.

Although treadmill stepping is well documented as an effective intervention for accelerating the acquisition of gait in children with DS,[6] few reports indicate translation of this protocol to clinical intervention for that population or for others. The use of the treadmill to increase leg activity in infants with SB has recently been reported.[1] However, in contrast to the delayed motor skill acquisition characteristic of DS, the delayed acquisition of gait in children with SB reflects neurological and orthopedic challenges that have to be accommodated to achieve functional outcomes. We propose that the translation of treadmill intervention for the population of infants and toddlers with SB must anticipate function with assistive devices and orthotics. Such integration had not been previously described for use of the treadmill with children who are preambulatory.

The acquisition of gait for this toddler occurred across an 18-week period, with acquisition of gait defined as an ability to use gait for activity and participation. At 23 months of age, the toddler in this study achieved gait on the earlier end of the 24 to 36 month age range reported in the literature for the onset of gait in children with an L4-L5 level lesion.[26-27] The fact that we used a more stringent definition of gait onset than is typically reported using a milestone approach, makes this outcome remarkable.

Parent report of the toddler's increased willingness to use her walker after initiation of treadmill stepping with weights, supports that this toddler responded to conditions that increased her sensorimotor experience and increased the demand for muscle activity from her legs. Previous research has shown that leg activity in utero exceeds the leg activity noted during postnatal development in these infants.[28] Clearly, intervention for infants and toddlers with SB has to both increase physical activity of the legs and relate this physical activity to functional outcomes. The functional mobility outcomes for this toddler support that her use of mobility as well as the distance she was able to ambulate improved during the period of this intervention.

Interestingly, the total estimated time per week spent stepping was about 25 minutes across all 3 phases of the study. This is less than the 40 minutes per week (8 min/d × 5 d/wk) that was achieved by toddlers with DS,[6] and still this toddler showed gains in gait during each phase of the intervention. Features of the treadmill intervention developed for toddlers with DS may not be appropriate to or achievable by toddlers with SB. Additional research is needed to establish parameters that are appropriate for toddlers with SB, and to guide decision making for progression of locomotor interventions.

The use of data from videotapes and parent logs to guide decisions to progress this intervention was intended to be supportive of clinical practice. Further, the intervention was designed to be family centered with the parents (1) setting the ambulatory goal and (2) identifying points when the intervention program needed to be progressed. The home-based intervention extended the protocol developed for children with DS.[6] The progression described may be applicable to other children with SB. With some modification to the algorithm presented in Figure 2, this progression may also be applicable to children with other types of neuromotor delay in the acquisition of gait and for whom incorporating assistive devices or orthotics may be required.

REFERENCES

1. Teulier C, Smith BA, Kubo M, et al. Stepping responses of infants with myelomeningocele when supported on a motorized treadmill. *Phys Ther*. 2009;89(1):60-72.
2. Adkins DL, Boychuk J, Remple MS, Kleim JA. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J Appl Physiol*. 2006;101:1776-1782.
3. Nudo RJ. Plasticity. *Neuro Rx*. 2006;3(4):420-427.
4. Adolph KE, Vereijken B, Shrout PE. What changes in infant walking and why. *Child Dev*. 2003;74(2):475-497.
5. Ulrich DA, Lloyd MC, Tiernan CW, Looper JE, Angulo-Barroso RM. Effects of intensity of treadmill training on developmental outcomes and stepping in infants with Down syndrome: a randomized trial. *Phys Ther*. 2008;88(1):114-122.
6. Ulrich DA, Ulrich BD, Angulo-Kinzler RM, Yun J. Treadmill training of infants with Down syndrome: evidence-based developmental outcomes. *Pediatrics*. 2001;108(5):1-7.
7. Bartonek A. Motor development toward ambulation in preschool children with myelomeningocele—a prospective study. *Pediatr Phys Ther*. 2010;22(1):52-60.

8. Behrman AL, Lawless-Dixon AR, Davis SB, et al. Locomotor training progression and outcomes after incomplete spinal cord injury. *Phys Ther*. 2005;85(12):1356-1371.
9. Cernak K, Stevens V, Price R, Shumway-Cook A. Locomotor training using body-weight support on a treadmill in conjunction with ongoing physical therapy in a child with severe cerebellar ataxia. *Phys Ther*. 2008;88(1):88-97.
10. Musselman KE, Fouad K, Misiaszek JE, Yang JF. Training of walking skills overground and on the treadmill: case series on individuals with incomplete spinal cord injury. *Phys Ther*. 2009;89(6):601-611.
11. Bayley N. *Bayley Scales of Infant and Toddler Development*. 3rd ed. San Antonio, TX: Psycho Corp; 2006.
12. Graham HK, Harvey A, Rodda J, Nattrass GR, Pirpiris M. The functional mobility scale (FMS). *J Pediatr Orthop*. 2004;24(5):514-520.
13. Haley SM, Coster WJ, et al. *Pediatric Evaluation of Disability Inventory (PEDI)*. PEDI Research Group, Boston, MA; 1992.
14. Bartonek A, Saraste H. Factors influencing ambulation in myelomeningocele: a cross-sectional study. *Dev Med Child Neurol*. 2001;43:253-260.
15. Findley TW, Agre JC, Habek RV, et al. Ambulation in the adolescent with myelomeningocele I: early childhood predictors. *Arch Phys Med Rehabil*. 1987;68:518-522.
16. McDonald CM, Jaffe KM, Shurtleff DB, Menelaus MB. Modifications to the traditional description of neurosegmental innervation in myelomeningocele. *Dev Med Child Neurol*. 1991;33:473-481.
17. Wiliams EN, Broughton NS, Menelaus MB. Age-related walking in children with spina bifida. *Dev Med Child Neurol*. 1991;41:446-449.
18. Swank M, Dias L. Myelomeningocele: a review of the orthopedic aspects of 206 patients treated from birth with no selection criteria. *Dev Med Child Neurol*. 1992;34:1047-1052.
19. Lariviere C, Delisle A, et al. The effect of sampling frequency on EMG measures of occupational mechanical exposure. *J Electromyogr Kinesiol*. 2004;15:200-209.
20. Thelen E, Ulrich BD. Hidden abilities. *Monographs Soc Res Child Dev*. 1991;56(1):Serial No 223.
21. Spencer JP, Thelen E. Spatially specific changes in infants' muscle coactivity as they learn to reach. *Infancy*. 2000;1:275-302.
22. Chang C-L, Kubo M, Buzzi U, Ulrich BD. Early changes in muscle activation patterns of toddlers during walking. *Inf Behav Dev*. 2006;29(2):175-188.
23. Staude G, Wolf W. Objective motor response onset detection in surface myoelectric signals. *Med Eng Phys*. 1999;21:449-467.
24. Lee AS, Cholewicki J, Reeves NP. The effect of background muscle activity on computerized detection of sEMG onset and offset. *J Biomech*. 2007;40:3521-3526.
25. Staude G, Flachenecker C, Daumer M, Wolf W. Onset detection and surface electromyographic signals: a systematic comparison of methods. *EURASIP J Appl Signal Processing*. 2001;67-81.
26. Aguilera S, Soothill P, Denbow M, Pople I. Prognosis of spina bifida in the era of prenatal diagnosis and termination of pregnancy. *Fetal Diagn Ther*. 2009;26(2):68-74.
27. Biggio JR, Jr, Owen J, Westrom KD, Oakes WJ. Can prenatal ultrasound findings predict ambulatory status in fetuses with open spina bifida? *Am J Obstetr Gynecol*. 2001;185(5):1016-1020.
28. Rademacher N, Black DP, Ulrich BD. Early spontaneous leg movement in infants born with and without myelomeningocele. *Pediatr Phys Ther*. 2008;20(2):137-145.
29. Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: Testing and Function, With Posture and Pain*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005.