Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol. 37 No. 1, January/February 2000
Pages 65–72

Compelled weightbearing in persons with hemiparesis following stroke: The effect of a lift insert and goal-directed balance exercise

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Abstract—The hypotheses have been tested that 1) symmetry of weightbearing in persons who have sustained a stroke could be improved by the addition of a lift to the shoe on the non-paretic lower limb and 2) compelled weightbearing resulting from the addition of a lift in conjunction with targeted exercise helps to overcome the learned disuse of the paretic limb. Weightbearing on the paretic side was measured in eight persons with hemiparesis during quiet standing and in conditions of compelled weight shift. Compelled weight shifts were applied with special lifts to the shoe on the non-paretic limb of the subjects. An increase in symmetrical weightbearing was recorded in conditions of compelled weight shifts: 10-mm lift provided the best symmetry of bipedal standing. We suggest that improved symmetry of bipedal standing obtained with the lift of the non-paretic limb would help in overcoming the learned disuse of the affected limb. Pre- and post-test results of a person with hemiparesis who was wearing a shoe lift on the non-paretic limb during a 6-week physical therapy program showed statistically significant improvement of walking speed, stride length, and weightbearing. Such findings support the idea of using compelled weightbearing via lifting and targeted exercise during treatment.

Key words: *gait, hemiparesis, posture, weightbearing.*

The material in this study is based upon work supported by the National Institutes of Health, National Center for Medical Rehabilitation Research, Bethesda, MD

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INTRODUCTION

Stroke is the leading cause of disability in the elderly and a significant source of disability in younger adults. The most common manifestations of stroke are deficits in motor control that involve abnormal synergistic organization of movements, impaired force regulation, muscle weakness, sensory deficits, and loss of range of motion.

One area that has received significant attention over the years is the effect stroke has on postural and balance function. It is a common observation that individuals with hemiparesis exhibit asymmetry in quasi-static standing postures and during functional movements (1–4). This asymmetry has been associated with impairments in balance and may contribute to disordered gait (3).

Despite conventional physical therapy to correct an asymmetrical standing posture, continued balance and gait dysfunction and disordered lower limb motor control may exist. We contend that weight asymmetry and impaired balance function may be a consequence of a learned disuse of the paretic leg. For example, initially, following a stroke a person with hemiparesis may be unable or reluctant to bear much weight through the paretic limb when significant paresis exists. Later, continued weight-bearing asymmetry may continue and foster a further disuse despite the probability that improved motor function in the lower limb has occurred.

It has been demonstrated in series of experimental studies that monkeys after unilateral forelimb deafferentation do not use the affected limb in the free situation. However, the same monkeys can use the deafferented limb after special training, such as operant conditioning (5–7) or while the intact limb is restrained (8,9). It was suggested that the use of the affected limb after a shock-like condition that follows deafferentation is accompanied by negative experiences, such as loss of food, loss of balance, and so forth. This has the effect of suppressing all behavior with the deafferented limb producing long-term conditions when the monkey learns not to use this limb at all.

The results gained from deafferented primate research were used to develop preliminary application to persons with chronic stroke. First introduced by Ostendorf and Wolf (10) to improve the amount of upper limb use in persons with hemiparesis, the technique is based on restraining the contralateral limb in a sling for a period of 2 weeks (so-called Constraint Induced Movement Technique). This technique forces people to use the affected upper limb and, as a result, to overcome the learned disuse mechanism. It was described that persons with chronic stroke who received the constrained treatment increased the number of specific tasks commonly carried out with their upper limb in the life situation (9).

Although the constraint-induced therapy has been used for treatment of persons after stroke, to our knowledge the application of this technique to the lower limb has not been investigated. In particular, the effect of forced loading of the affected lower limb on balance and locomotion of persons with stroke has not been determined.

The purpose of this study was to 1) evaluate the effects of compelled weight shift induced by a lift to the shoe on the stronger (non-paretic) side on the weightbearing in a group of subjects with hemiparesis following stroke, and 2) estimate the effect of compelled weight shift in a targeted stroke balance retraining program.

METHODS

Subjects

Eight subjects with hemiparesis associated with unilateral stroke (6 males and 2 females, mean age 59.1±6.1 years, 4 had right and 4 left hemiparesis) participated in the study. The mean time from onset was 1.46±0.7 years with a range of from 0.16 to 5 years. All subjects were ambulatory with an assistive device and had no other known neuromuscular disabilities. All participants signed informed written consent.

Apparatus

Weightbearing of subjects was assessed using the Balance Master computerized force platform system (Balance Master, NeuroCom International, Clackamas, OR). This system consists of two force platforms connected to a personal computer allowing independent measurement of vertical forces between the feet and surface of the platforms. The subjects stood on the two force platforms with feet positioned using the manufacturer's protocol (each medial malleolus with the transverse force platform line, and the outside border of the heel with the height-appropriate line marked on the force platform). Five subjects wore a rigid polypropylene ankle-foot orthosis, which had been prescribed by their physiatrist, on the paretic leg and used their regular shoes. The subjects were instructed to stand upright with their arms at their sides and to keep their eyes open while looking straight ahead.

Procedure

Five series of measurements of weightbearing were performed. In the first series, the subjects were asked to stand on the force platforms while their weight-bearing distribution was recorded. During the next three series, the subjects were asked to stand with their stronger (non-paretic) leg on a small lift positioned on the surface of the force platform directly beneath the foot (**Figure 1**). Three lift sets made of plastic, extending the full length of the shoe and having different heights (7, 10, and 13 mm) were used. The lift sets were replaced in such a way that alignment of the feet on the force platforms did not change. The fifth series was similar to the first in that the subjects stood on the force platforms with no lift set. The same instructions to stand on the force platforms naturally and comfortably in accordance with the Balance Master protocol for foot position were provided to the subjects during all the experimental series. We expected the lifting of the stronger (non-paretic) leg of the subject to shift the center of gravity of the body toward the weaker (paretic) leg. Three measurements were performed in each series. There was a rest interval of approximately one-minute between each series. The order of the experimental series involving lifts of the stronger (non-paretic) leg was randomized among the subjects, however all of the subjects started and finished with a no-lift condition (series #1 and #5). An experimenter was always standing near the subjects so that the subjects had no fear of falling. No assistive devices were used during the testing procedures.

After the weightbearing test series was completed, one of the subjects (a 48-year-old with left hemiparesis) participated in a 6-week physical therapy program. A small shoe lift consisting of a three-layer inner sole (10-mm maximum) was made from cork and foam and was positioned into the right shoe of the subject at the beginning

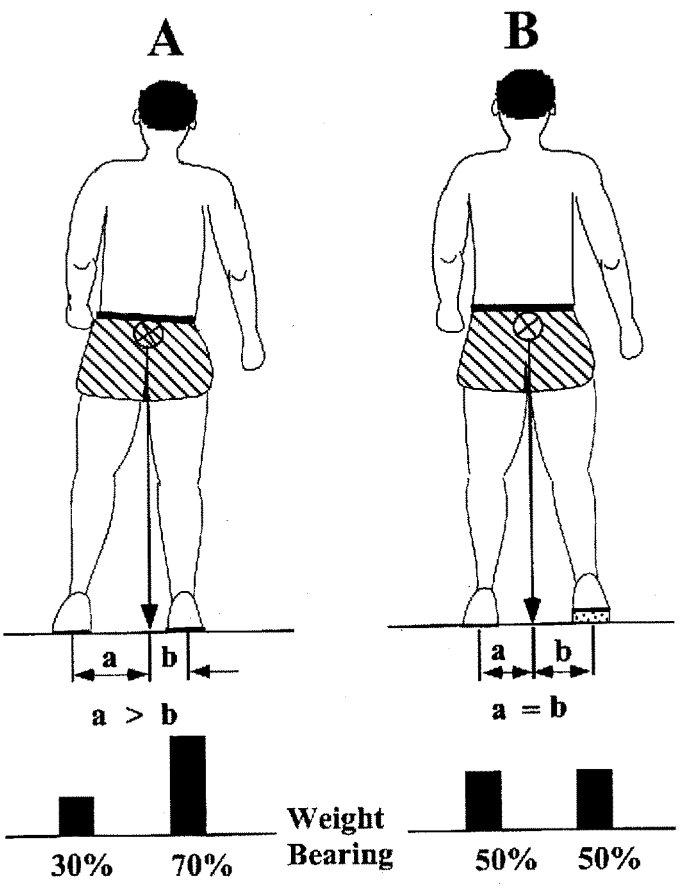

Figure 1.
Asymmetry of weightbearing and a remote position of the gravity line from the center of the base of support (surface surrounding the two feet) are common in hemiplegic individuals (A). Lift directly beneath the foot of the non-affected limb provides compelled shift of the gravity line toward the affected limb and results in more symmetrical weightbearing (B). Weightbearing is in percentage of the body weight.

of a training program. The subject was asked to wear the shoes with installed innersole all day and during all daily activities throughout the duration of the training program. This included during leisure time as well as during physical therapy. The subject was tested in the Motion Analysis Laboratory three times (prior to and after the wearing of the lift and 10 weeks after treatment was finished). The laboratory testing consisted of the subject walking normally with a cane at his comfortable walking speed across a 10-m walkway. No lift insert was used during any of the three gait tests. The time of crossing 5 m along this walkway was recorded with optoelectronic sensors positioned on tripods ("beam break detectors"). Step length parameters were collected by a step print technique (11). Data from three walking trials for each test were collected and analyzed. A personal computer with customized software based on the LabView-4.1 package was used to control the experiment, collect the data, and perform most of the analyses.

The physical therapy treatment protocol included exercises specifically designed to target paretic limb muscle performance within the context of several goal-directed activities in standing under a compelled weight-bearing situation. A Leg Exerciser (12), designed as a base plate with adjustable height of one side and two rotating disks on which the subject was positioned and to which he was imparting rotary movements, was also used during the treatment intervention to focus movement control of the paretic limb (**Figure 2**). The advantage to such a device is that it affords paretic limb muscle training in an upright position with the limb loaded.

The physical therapy program incorporated a series of activities that were developed so that the subject could perform an independent/supervised home exercise program in conjunction with the constant use of the lift insert. The activities were adapted from those highlighted by Sax et al. (13), in an effort to produce dynamic weight transfer using a variety of goal-directed movements. These activities included standing leg flexion, lateral trunk flexion, gait initiation (two steps forward), a hip shift maneuver, and lateral leg raising with a step (13). Additionally, sit-to-stand was practiced and an isometric hip abduction maneuver in standing was incorporated into the treatment protocol. Although emphasis was placed on movement using the weaker limb to initiate rapid goal-directed movements, these activities were performed to both sides and at varying speeds of movement where applicable. These activities were incorporated into all physical therapy treatment sessions and the subject was encouraged to perform as many of these as possible throughout his day in any order.

Prior to the start and at the end of the treatment, a clinical assessment using the Fugl-Meyer Lower Extremity Assessment (14) and the Balance Scale (15) was performed.

Data Processing

Weightbearing data on the weaker side were collected and averaged. The time of crossing a light marker (described above) was collected and used for calculation of velocity of gait. Step length was collected and averaged from footprints obtained during laboratory tests.

One-way repeated measures ANOVA were used to investigate the degree of change in weightbearing over the five experimental series including different lift conditions. Student's t tests were used to compare test performances of the subject participating in the physical therapy exercise program. Significance was in all cases set at $p<0.05$.

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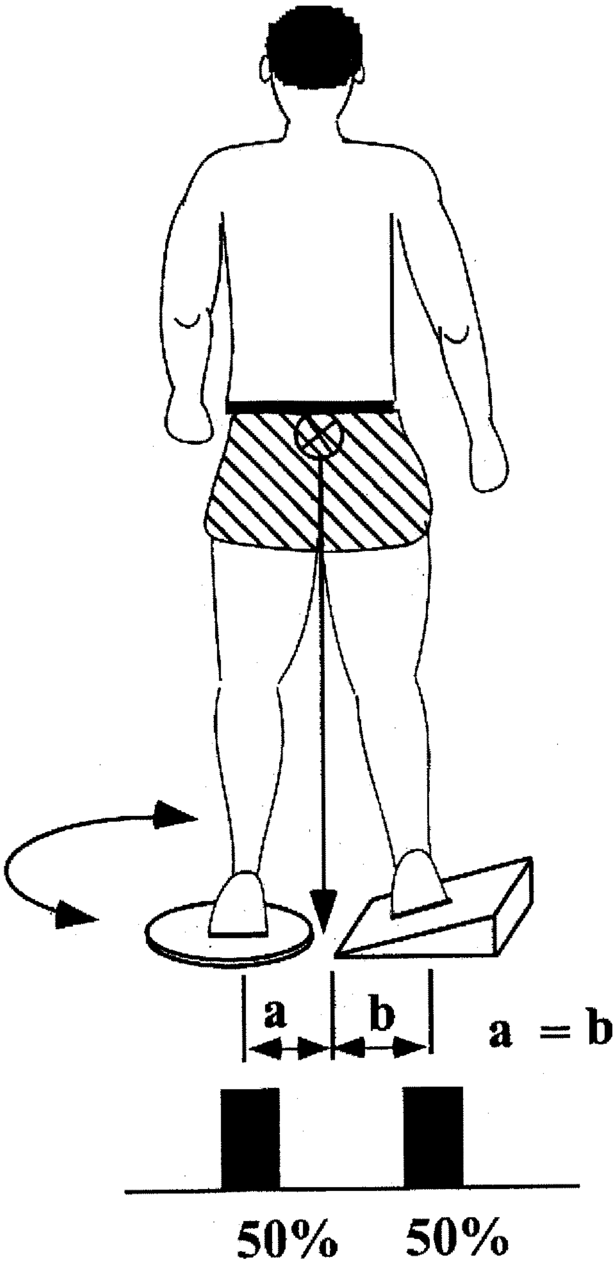

Figure 2.
The leg exerciser provides compelled weightbearing on the affected limb while the subject imparts rotary movements to the disk. One disk is shown for simplicity. Note more symmetrical position of the gravity line and more equal weight distribution during dynamic activity.

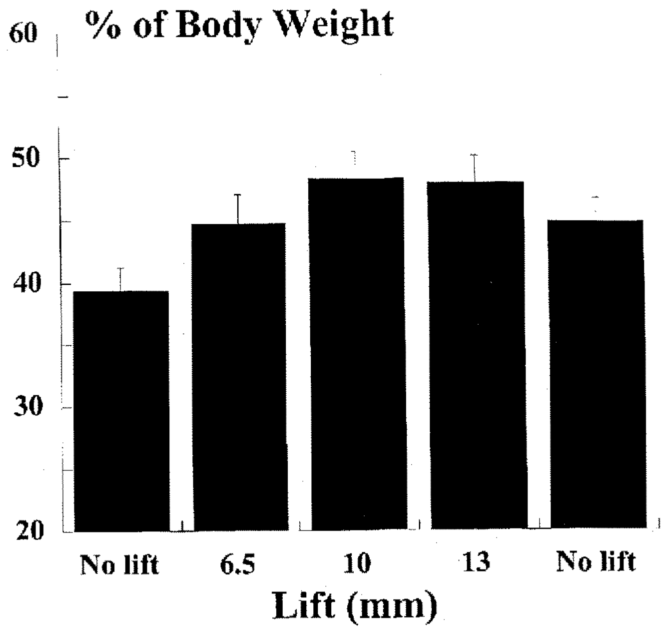

Figure 3.
Averaged across eight subjects, weightbearing measured on the paretic side with standard errors bars. Note changes in weightbearing with increase of height of lifts and carryover effect seen in the increased magnitude of the weightbearing measured after lifts were removed. Weightbearing scale is in percentage of the body weight.

RESULTS

All subjects demonstrated asymmetrical weightbearing with the weaker (paretic) limb relatively unloaded while standing on the force platforms. The average weightbearing measured on the affected side (no lift situation) was 38.8±1.8 percent of body weight. While standing with their stronger (non-paretic) leg on a lift positioned on the surface of the force platform the asymmetry of weightbearing was improved (**Figure 3**). The symmetry of the weightbearing increased gradually with increasing lift height reaching almost 50-50 weight distribution at the 10-mm lift condition. Single-factor ANOVA demonstrated significant effects of the leg lifting for all three lift heights ($F_{7,3}$=11.08, $P<0.05$). When weightbearing with no lift was measured for the second time (recall this occurred during the same session in the last [fifth] condition), there was a significant carryover effect seen as a maintained increase in weightbearing on the paretic side. Averaged value of percent of body weight measured on the paretic side was larger than measured in the first series with no lift ($F_{7,1}$=8.57, $P<0.05$).

In the case study, weightbearing and gait parameters of the 48-year-old subject with left hemiparesis were measured three times, prior to the start of the treatment (Test #1), 4 days after the treatment was completed (Test #2), and 10 weeks after the completion of treatment (Test #3).

The results of tests are presented in **Table 1** and **Figure 4**. The percentage of the body weight measured on the weaker side with no lift prior to treatment was 33.7±1.2 and it improved, increasing significantly, to 39.7±0.9 after

Table 1.
Changes in weightbearing and gait parameters with treatment.

Tests	Weight-bearing	Gait velocity	Stride length
PreTest	33.7±1.2	28.34±0.1	0.86±0.001
PostTest 1	39.7±0.9	32.33±0.49	1.03±0.002
PostTest 2	39.3±2.18	32.38±0.37	0.97±0.001

Weightbearing on the affected limb, in percent; Gait velocity in meters per minute; Stride length in meters; PostTest 1 is after intervention; PostTest 2 is 10 weeks after intervention.

treatment (t= -10.4, P>0.05). There was a carryover effect seen in weightbearing measured during the third test (39.3±2.18); however, it was just under the level of significance for this third test (t= -3.21, P=0.08, two-tailed, paired Student's *t-test*).

The mean gait velocity measured (no lift) was 28.34±0.1 m/min at the time of first testing and it reached 32.33±0.49 m/min during the second test and remained the same at the time of the third test, reaching 32.38 ±0.37 m/min. There was statistically significant improvement in gait velocity as a result of therapy (Test #1 and #2, t= -6.1, P<0.05, two-tailed, paired Student's *t-test*). Gait velocity measured 10 weeks after the therapy was finished was still above the magnitude measured prior to the start of therapy (t= -463, P>0.05).

The initial stride length measurement for the paretic limb was 0.86±0.001 m and reached 1.03±0.002 m at the end of treatment. In 10 weeks, the stride lengths decreased and reached 0.97±0.001 m. There was statistically significant improvement of gait stride length after therapy (t= -114.3, P<0.05, two-tailed, paired Student's *t-test*). There was also a statistically significant difference between stride length measured prior to treatment and at 10 weeks post-treatment (t= -71.6, P<0.05, two-tailed, paired Student's *t-test*).

Two additional clinical measurements were also performed: the Fugl-Meyer Lower Extremity Assessment (14) and the Balance Scale (15). The lower limb score was initially 15/34. The score was 18/34 at the end of the 6-week treatment program and 19/34 at the 10-week post-treatment evaluation. Improvements in paretic lower limb performance were attributable to improvements in active knee flexion control in sitting and standing. The initial Balance Scale score was 43/56. The balance score at the end of the 6-week treatment program was 46/56 and 47/56

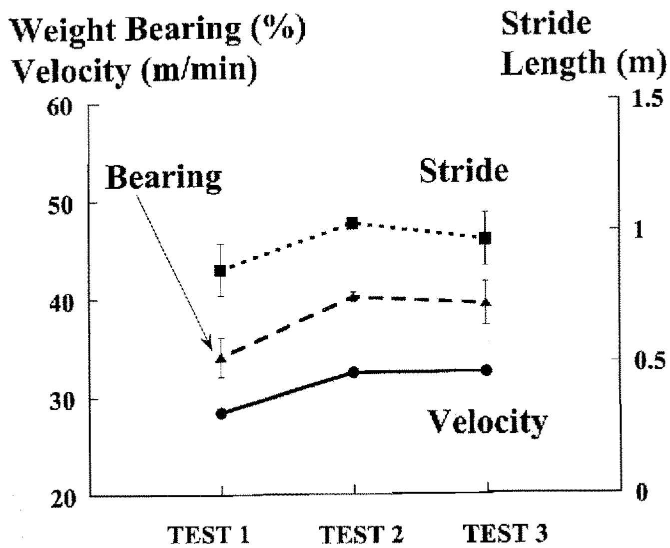

Figure 4.
Weightbearing measured on the paretic side, gait velocity, and stride length of one of the subjects measured prior to starting treatment involving compelled weightbearing (Test 1), immediately after the end of treatment (Test 2) and 10 weeks after treatment was finished (Test 3). Note the increase in the magnitudes of all three parameters with the treatment. Standard error bars are shown.

at the 10-week post-treatment evaluation. Improvements in this score were attributable to changes in sit-to-stand, reaching, narrow standing, and unilateral standing capability.

DISCUSSION

In this preliminary and exploratory study, we used lifting of the stronger leg to improve symmetry of weightbearing during quiet standing in a sample of individuals with hemiparesis. The application of a lift to the non-paretic limb induced equidistance of the projection of the center of gravity line from each foot as defined by the static measurement of weight distribution beneath the feet. All subjects showed improved symmetry of weightbearing even when using a small elevation of their stronger limb. Weightbearing symmetry was gradually improved with increasing lift size from 0 to 10 mm. There was no statistical difference in the effect of two sized lifts (10 and 13 mm) on the symmetry of weightbearing suggesting that 10-mm lift was probably well-suited to the subjects' body dimensions. In a case study of one individual, we found that a simple but targeted exercise program used in conjunction with a lift insert improved the functional performance of the person with hemiparesis.

Weightbearing during Quiet Standing

Muscle weakness, impaired postural control, and impaired body proportions may affect symmetry of weightbearing and postural stability. For instance, lower leg amputation is associated with a severe asymmetry of mass and muscle power resulting in asymmetrical loading and lateral instability (16). Muscle weakness and impaired postural control in individuals with cerebrovascular accidents lead to decreased weightbearing on the weaker lower limb resulting in abnormal stance stability (2,17). Thus, asymmetric loading has been described as one of the sources contributing to disordered hemiparetic gait (3). A significant relationship between maximum weightbearing through the paretic lower limb and paretic lower limb strength has been described (18).

Several studies of weightbearing in persons following stroke confirm that re-educating symmetrical stance is important in improving balance control (19–23). It also has been shown that individuals following stroke were able to bear more than 50 percent of their weight through their paretic lower limb when requested to do that (24) and can increase (beyond what is natural) their weightbearing through the weaker limb during sit-to-stand maneuvers (25). Different techniques have been used in physical therapy treatment including visual, tactile, or verbal cues or postural feedback devices to improve weight loading on the paretic limb (4,21,23).

The results of the present study demonstrate that there was an adaptation effect seen as an increase in weight applied to the affected limb after the lifts to the non-affected limb were removed. This result was intriguing to us because it demonstrated an ability of the subjects not only to modify their posture to a new environmental condition (increasing shoe lift) and redistribute their body weight more symmetrically, but to keep a more symmetrical weight-bearing position after the environmental constraints were removed. Thus, the results of the first part of the study support the idea that lifting of the stronger limb could improve weight-bearing symmetry. The results also suggest that these subjects with asymmetry of weightbearing who showed improvement in static weight-bearing symmetry while their stronger limb was lifted, could be receptive to the special treatment directed toward reduction in standing-balance asymmetry applied in the second part of this study.

The question whether a lift to the shoe involves artificial leg-length inequality stressing one of the limbs more than another could be raised. Indeed, we may expect that even a small lift to one shoe may change the symmetry of bipedal standing and gait. However, some degree of asymmetry is present in every human being and it is considered the normal variant (26). In fact, the detriment caused by leg-length inequality of less than 25 mm is considered as cosmetic rather than an etiological factor in the pathogenesis of stress features in the lower extremities (27,28). In our study, the maximal lift to the shoe was only 13 mm as compared with inequalities approaching 25 mm, which frequently escape observation (28).

The discussion regarding the effect of quasi-static standing balance training on reducing the asymmetry of movements associated with hemiparetic locomotion is not finished yet. There are published reports supporting both the effect of weight-bearing symmetry retraining exercises on locomotion of hemiparetic adults (19,29) and lack of improvement in locomotor performance in patients who improved standing posture after treatment (4). Due to the transient application of a lift set to the stronger limb of our sample of subjects, we would not expect to see any long-term carry over effects in our subjects based on the results of a single and brief application of a compelled weightbearing scenario. Rather, we would consider the results of improvements in weight-bearing symmetry with lift to the shoe of the stronger limb as an illustration of a possible direction of standing balance re-training therapy in individuals with hemiparesis.

Changes in Gait Parameters

Since loss of walking ability is a major problem after stroke, recovery of gait is a priority goal for most people. In our single subject case study, we monitored stride length and gait velocity of the subject who participated in treatment involving a compelled weight-bearing protocol. Gait velocity was measured because it is 1) considered an appropriate measure for documenting recovery of walking after stroke (30), 2) sensitive to the stage of recovery (31), and 3) positively correlated to strength (32) and scores obtained in clinical tests of function such as the Fugl-Meyer, Barthel, and Berg tests (33,34). These suggest that gait velocity could be used to reflect physiological and functional changes seen as a result of locomotor recovery (35). Changes in weightbearing during quiet standing with treatment were monitored as well. The results showed improvement in all three parameters at the end of the intervention, which involved compelled loading of the affected limb during daily activities and elements of compelled weightbearing during physical therapy sessions and self-performed exercises at home.

It is important to mention that gait velocity was measured with no lift insert in all gait tests, suggesting that there was no direct effect of the artificial leg-length inequality induced by a lift insert on measured gait velocity.

Thus, improvement of gait velocity seen after treatment could be addressed as a result of intervention involving elements of compelled weightbearing.

By conducting a second post-test at 10 weeks after the end of therapy, we wanted to find out whether improvement in posture and gait remained. The results were quite positive: weightbearing on the affected limb and stride length were slightly lower than after the end of therapy, but they remained higher than before therapy was started. The subject was more stable when the therapy was finished, able to move the paretic lower limb better, and was walking longer distances as measured by self-report. The fact that the subject continued the home exercise program of targeted weight-transfer activities with the lift and that he continued and increased his volunteer community service involvement may explain the stability of his gait velocity and other clinical scores seen during the third (follow-up) test. It is important to note that improvements in gait velocity and stride length occurred in this subject despite an absence of gait training in the training protocol. The ongoing execution of walking was never practiced in physical therapy treatment sessions, nor were any instructions provided related to modifying the subject's gait pattern.

Improvements in walking function were not found in a study by Winstein et al. (4), despite improvements in stance symmetry following quasi-static balance re-training in a group of individuals with hemiparesis. Our approach in this exploratory analysis was different in that we incorporated compelled weightbearing through the incorporation of a lift beneath the stronger limb, which promoted weight shift during all daily activities. Additionally, the application of a Leg Exerciser practice focused training toward the activation of paretic hip musculature in standing, and the inclusion of goal-directed activities forced *dynamic weight transfer* and movement training in both limbs across a variety of speeds such that learned disuse was improved. Improvements in the Fugl-Meyer Lower Extremity and Balance Scale scores would appear to support improvements in the effective use of the paretic lower limb within the context of balance-related activities. Taken collectively, it is promising that a program emphasizing compelled weightbearing during a variety of goal-directed tasks that share a similar organization at the level of ground reaction force production (13) did result in improvement in locomotor performance in this individual.

As it was suggested by Taub and Wolf (9), the learned disuse of the affected limb could be a cause of lack of progress in recovery in some individuals with stroke. This fact taken, together with a common view that persons with chronic stroke reach a plateau in their motor recovery in a year after brain damage and are unlikely to exhibit any further improvement for the rest of their lives (36), emphasizes the importance of finding new treatment approaches for such people. The results of this clinical observation convince us that a compelled weight-bearing protocol is one such approach designed to facilitate enhanced movement in the involved lower limb.

CONCLUSION

A compelled weightbearing-oriented program for normalization of weightbearing over the impaired lower limb may have a positive effect on stance and gait of individuals with hemiparesis. The advantage of a compelled weight-bearing technique is that the lift to the stronger (non-paretic) limb used during daily activities of a patient at home may help in overcoming the learned disuse of the paretic leg. Moreover, our clinical observation in one subject suggests that the application of an intervention program focused on compelled weightbearing may contribute to improved postural control and gait performance in persons with hemiparesis.

REFERENCES

1. Bohannon RW, Larkin PA. Lower extremity weight bearing under various standing conditions in independently ambulatory patients with hemiparesis. Phys Ther 1985;65:1323–5.
2. Pai YC, Rogers MW, Hedman LD, Hanke TA. Alterations in weight-transfer capabilities in adults with hemiparesis. Phys Ther 1994;74:647–59.
3. Wall JC, Turnbull GI. Gait asymmetries in residual hemiplegia. Arch Phys Med Rehabil 1986;67:550–3.
4. Winstein CJ, Cardner ER, McNeil DR, Barto PS, Nicholson DE. Standing balance training: effect on balance and locomotion in hemiparetic adults. Arch Phys Med Rehabil 1989;70:755–62.
5. Taub E, Goldberg IA, Taub PB. Deafferentation in monkeys: pointing at a target without visual feedback. Exp Neurol 1975;46:178–86.
6. Taub E, Ellman SJ, Berman AJ. Deafferentation in monkeys: effect on conditioned grasp response. Science 1966;151:593–4.
7. Wylie RM, Tyner CF. Performance of a weight-lifting task by normal and deafferented monkeys. Behav Neurosci 1989;103:273–82.
8. Knapp HD, Taub E, Berman AJ. Movements in monkey with deafferented forelimbs. Exper Neurol 1963;7:305–15.
9. Taub E, Wolf SL. Constrain induced movement techniques to facilitate upper extremity use in stroke patients. Top Stroke Rehabil 1997;3:38–61.
10. Ostendorf CG, Wolf SL. Effect of forced use of the upper extremity of a hemiplegic patient on changes in function. Am Phys Ther Assoc 1981;61:1022–8.

11. Boenig DD. Evaluation of clinical method of gait analysis. Phys Ther 1977;57:795–8.
12. Aruin AS. Leg exerciser and method. USA Patent #5,879,275 (1999).
13. Sax DM, Getts EA, Hoke MC, et al. Is there a common organization of lateral weight transfer for a variety of goal directed movements? Phys Ther 1993;73:Suppl:39.
14. Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient: I. a method for evaluation of physical performance. Scand J Rehabil Med 1975;7:13–31.
15. Berg K, Wood-Dauphinee S, Williams JJ. The balance scale: reliability assessment with elderly residents and patients with acute stroke. Scand J Rehabil Med 1995;27:27–36.
16. Geurts CH, Mulder TW, Nienhuis B, Rijken AJ. Dual-task assessment of reorganization of postural control in persons with lower limb amputation. Arch Phys Med Rehabil 1991;72: 1059–64.
17. Mizrahi J, Solzi P, Ring P, Nisell R. Postural stability in stroke patients: vectorial expression of asymmetry, sway activity and relative sequence of reactive forces. Med Biol Eng Comput 1989;27:181–9.
18. Bohannon RW. Relationship among paretic knee extension strength, maximum weightbearing, and wait speed in patients with stroke. J Stroke Cerebrovasc Dis 1991;1:65–9.
19. Dickstein R, Nissan M, Pillar T, Scheer D. Foot-ground pressure pattern of standing hemiplegic patients. Phys Ther 1984;64: 19–23.
20. Sackley CM. Falls, sway, and symmetry of weight-bearing after stroke Int Disabil Stud 1991;13:1–4.
21. Shumway-Cook A, Anson D, Haller S. Postural sway biofeedback: its effect on re-establishing stance stability in hemiplegic patients. Arch Phys Med Rehabil 1988;69:395–400.
22. Sackley CM, Lincoln NB. Weight distribution and postural sway in healthy adults. Clin Rehabil 1991;5:181–6.
23. Sackley CM, Baguley BI, Gent S, Hodson P. The use of a balance performance monitor in the treatment of weight-bearing and weight-transference problems after stroke. Physiotherapy 1992;78:907–13.
24. Bohannon RW, Tinti-Wald D. Accuracy of weight-bearing estimation by stroke versus healthy subjects. Percent Motor Skills 1991;72:935–41.
25. Engardt M, Oisson E. Body weight-bearing while rising and sitting down in patients with stroke. Scand J Rebabil Med 1992;24: 67–74.
26. Kostuik, JP, Bentivoglio J. The incidence of low back pain in adult scoliosis. Spine 1981;6:268–73.
27. Gross RH. Leg length discrepancy: how much is too much? Orthopedics 1978;1:307–10.
28. Friberg O. Clinical symptoms and biomechanics of lumbar spine and hip joint in leg length inequality. Spine 1983;8:643–51.
29. Lane RE. Facilitation of weight transference in the stroke patient. Physiotherapy 1978;64:260–4.
30. Goldie PA, Matyas TA, Evans O. Deficit and change in gait velocity during rehabilitation after stroke. Arch Phys Med Rehabil 1996;77:1074–82.
31. Brandstater ME, de Bruin H, Gowland C, Clark BM. Hemiplegic gait: analysis of temporal variables. Arch Phys Med Rehabil 1983;64:583–7.
32. Bohannon RW. Strength of lower limb related to gait velocity and cadence in stroke patients. Physiother Can 1986;38:204–8.
33. Dettman MA, Linder MT, Sepic SB. Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient. Am J Phys Med 1987;66:77–90.
34. Skilbeck CE, Wade DT, Hewer RL, Wood VA. Recovery after stroke. J Neurol Neurosurg Psych 1983;46:5–8.
35. Richards CL, Malouin F, Dumas F, Tardif D. Gait velocity as an outcome measure of locomotor recovery after stroke. In: Clark RL, Oatis CA, editors. Gait analysis, theory and application. St. Louis: Mosby; 1995. p. 356–64.
36. Parker VM, Wade DT, Lanton HR. Loss of arm function after stroke: measurement, frequency, and recovery. Int Rehabil Med 1986;8: 69–73.

Submitted for publication March 30, 1999. Accepted in revised form May 18, 1999.