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Original Article

The Effect of Increasing Weight Bearing on the Paretic Side on Pattern of Muscular Activity During Walking in Stroke Patients

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ABSTRACT

Background: Gait disorder is a common motor complication after stroke. Studies have revealed that conventional physiotherapy cannot manage this disorder efficiently; therefore, more studies regarding efficient treatment protocols are crucial. The purpose of this study was to investigate the effect of compelled weight-bearing approach on muscle activation patterns during walking in individuals with stroke.
Methods: 24 hemiparetic patients participated in this study. Patients were randomly divided into 2 groups: experimental and control. The experimental group received increased weight bearing on the paretic leg via a shoe lift in addition to physical therapy for 6 weeks. The control group received only physical therapy. Laboratory assessments included weight-bearing symmetry ratio and electromyographic parameters recored from the medial gastrocnemius, tibialis anterior, rectus femoris and biceps femoris. The amplitude and duration of electromyographic activity for each subject was then calculated during the stance and swing phases of their gait cycle. All measurements were compared within and between groups after the termination of treatment.
Results: After treatment, weight-bearing symmetry ratio improved significantly in the experimental group. Additionally, the electromyographic activity of paretic medial gastrocnemius increased significantly during the stance phase while activity duration of paretic rectus femoris decreased significantly in swing phase. In the control group, the weight-bearing symmetry ratio didn't change significantly. Only activity duration of non-paretic rectus femoris decreased significantly in swing phase.
Conclusion: The results show that compelled weight bearing on the paretic side improve amplitude and the timing for activity of some muscles in the lower limbs during walking.

Introduction

During human walking, the muscle activity of the lower extremities needs to be coordinated in order to provide support, dynamic balance, propulsion and toe clearance in different phases of each gait cycle. To achieve these goals, proper amplitude and timing of lower extremity muscle activity is crucial [1,2].

Following hemiparesis resulting from stroke, neuromuscular control of walking undergoes significant changes, which may include muscle weakness on the contralateral side of the body due to a lesion. Adaptive changes in activity patterns of the non-paretic lower limb muscles along with dramatic changes in the temporal organization of muscle activity in both lower limbs has been shown [3-6].

Despite large differences between patients, some common abnormalities have been observed in lower limb muscle activity patterns following a stroke [7]. These

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abnormalities include premature activity of the paretic calf muscles during stance phase, an overall decrease in EMG activation amplitude of paretic side, and co-activation that spreads to several or all muscle groups in both paretic and non-paretic limbs to compensate for paretic lower limb muscular weakness [7].

Abnormal muscle activity patterns appear from 1 to 10 weeks post-stroke and often remain despite some degree of motor performance improvement after a common rehabilitation program [5,6]. These abnormalities which determine the quality and functional limitation of the hemiparetic gait pattern are also detected in chronic stroke patients who can ambulate and walk without assistive devices [8,9]. Therefore, an effective treatment program for gait impairments following stroke must consider these neuromuscular timing abnormalities, how they change, and how they can be modified over the course of gait recovery.

Evidence demonstrated that the role of load bearing is critical for determining the timing as well as the amplitude of muscular activity during gait [10,11].

In this regard, clinical evidence indicates that most stroke patients tolerate more body weight on their non-paretic side [12]. Some researchers believe that weight-bearing asymmetry in stroke patients is a consequence of “learned nonuse” from the paretic limb [13]. Initially, should significant paresis exist, these patients might be unable to bear weight on the paretic lower limb. Subsequently, patients continue to exhibit weight-bearing asymmetry, despite improved motor function in the lower extremity, fostering future disuse of the paretic limb [13].

Constraint Induced Movement Therapy (CIMT) is a treatment approach used to overcome “learned nonuse”. This treatment approach produced considerable positive results in improving motor function of the paretic upper limb in individuals with stroke [14,15]. Although this approach can be effective in the rehabilitation of upper limbs, it cannot be used in gait rehabilitation for hemiparetic stroke patients because restraint of the intact lower limb will disable walking functions [13]. However, the concept of forced use of the paretic side can be applied to the lower limbs.

Using shoe wedge or lift is a method employed by researchers for compelled weight bearing on the paretic lower limb in individuals with stroke [16]. Compelled body weight shift approach is based on mechanically shifting the body weight toward the affected side [17]. The results of a study by Aruin et al. demonstrated increased weight-bearing symmetry and gait velocity after long term use of shoe lift by the non-paretic leg in chronic stroke patients [13]. Mohaprata also indicated improvement of motor recovery and gait velocity following compelled weight-bearing approach in individuals with acute stroke [18].

Based on these pieces of evidence and given the importance of gait rehabilitation in stroke patients, in the present study we utilized a lift under non-paretic leg for increasing weight bearing and increasing the use of the paretic limb in conjunction with physical therapy in patients with stroke. The results of this program was assessed through electromyographic activity changes of lower limb muscles during the gait cycle.

The aim of this study was to assess the changes of amplitude and timing of paretic and non-paretic lower limb muscles during stance and swing phases of gait cycle after compelled weight bearing on the paretic side.

Methods

Subjects: Twenty four individuals with hemiparesis resulting from stroke participated in this study. Informed consent was obtained from all subjects. The inclusion criteria were: chronic hemiparesis due to stroke, first stroke experience, weight-bearing asymmetry, and the ablility to walk without assistive devices. Exclusion criteria were: unstable medical conditions, inability to understand and follow the instructions, and any orthopaedic or neurological disorders in addition to stroke.

Patients were also tested on the Berg Balance Scale for providing a standard measure of functional balance [19]. In addition, the Modified Ashworth Scale assessed spasticity of the ankle, where 0 indicated no increase in muscle tone while a score of 4 reflected rigidity of the affected part in flexion or extension [20]. Table 1 summarizes the patient characteristics.

Measurements: Weight-bearing symmetry ratio was measured in both groups before and after treatment using two force platforms (Bertec-MBM 4060) while patients stood normally on force plates with one foot on each plate and arms hanging loosely by their sides [21]. Symmetry ratio, reflecting the weight bearing status of the subjects was calculated according to:

$R=WI/WP$

Where R is the symmetry ratio, WI is weight bearing of the intact lower extremity and WP is weight bearing of the paretic lower extremity [22]. Three measurements were recorded and the average of symmetry ratio was calculated.

Electromyographic recordings were made using skintact surface electrodes with an inter-electrode distance of 20 mm [23]. Four lower extremity muscles were selected to record biceps femoris (BF), rectus femoris (RF), gastrocnemius medialis (GM), and tibialis anterior (TA) from both legs . The electromyographic activity of these muscles was recorded while patients walked at least 10 meters without shoes at a self-selected speed.

Electromyography signals were recorded with a sampling frequency of 1000 Hz and bandwidth frequency of 25-500 Hz and stored on a computer hard disk for offline processing.

The gait cycle was separated into its distinct phases, including the stance and swing phases. The stance and swing durations were determined with Footswitches (attached to the toe and heel regions) synchronized with electromyographic recordings. The fourth cycle of gait determined with Footswitches was selected for analysing EMG recordings. Six measurements were recorded for each patient.

Intervention: Patients were randomly divided into 2 groups: experimental and control. The experimental group, received compelled weight bearing on the paretic

Table 1: Participant characteristics

	Experimental group	Control group
Gender (M/F)	7/5	6/6
Age (years)	58.72 (4.28)	56.64 (5.1)
Height (cm)	171.15 (6.25)	168.28 (5.33)
Weight (kg)	71.32 (8.35)	69.13 (9.27)
Time since stroke (months)	13.26 (3.7)	15.68 (3.2)
Hemiparetic side, R/L	8/4	7/5
Dominant lower limb side, R/L	15/0	15/0
Stroke type (Ischemic/Hemorrhagic)	10/2	11/1
NIHSS	5.23 (1.75)	4.86 (1.31)
Berg Balance Scale, maximum56	48.32 (4.2)	47.81 (3.9)
Modified Ashworth Scale of ankle plantar flexors, maximum4	2	2

Values are mean (S.D.) for Age, Height, Weight, Time since stroke, Berg Balance Scale and NIHSS. Median for Modified Ashworth Scale. Number for gender, hemi-paretic side, dominant lower limb side and stroke type. †Abbreviations: M , male; F, female; R, right; L, left; NIHSS, National Institute of Health Stroke Scale

side via wearing the shoes with a 6 mm full-shoe insoles installed on the unaffected lower limb. Patients wore these shoes during all day activities [13,18].

The second part of treatment in this group was physical therapy. Therapy consisted of training 2h/day for 6 consecutive weekdays. Physical therapy consisted of: 1) strengthening exercises and range of motion or stretching exercises, particularly for soleus, gastrocnemius, hamstrings and hip flexors and aerobic conditioning 2) resolving functional limitation such as balance activities and re-education of functional walking [24,25]. The control group received only physical therapy with the same intensity and duration as the experimental group. Figure 1. Shows the flow diagram of the study.

Analysis: Duration of electromyographic activity for each muscle in each phase of the gait cycle (onset and

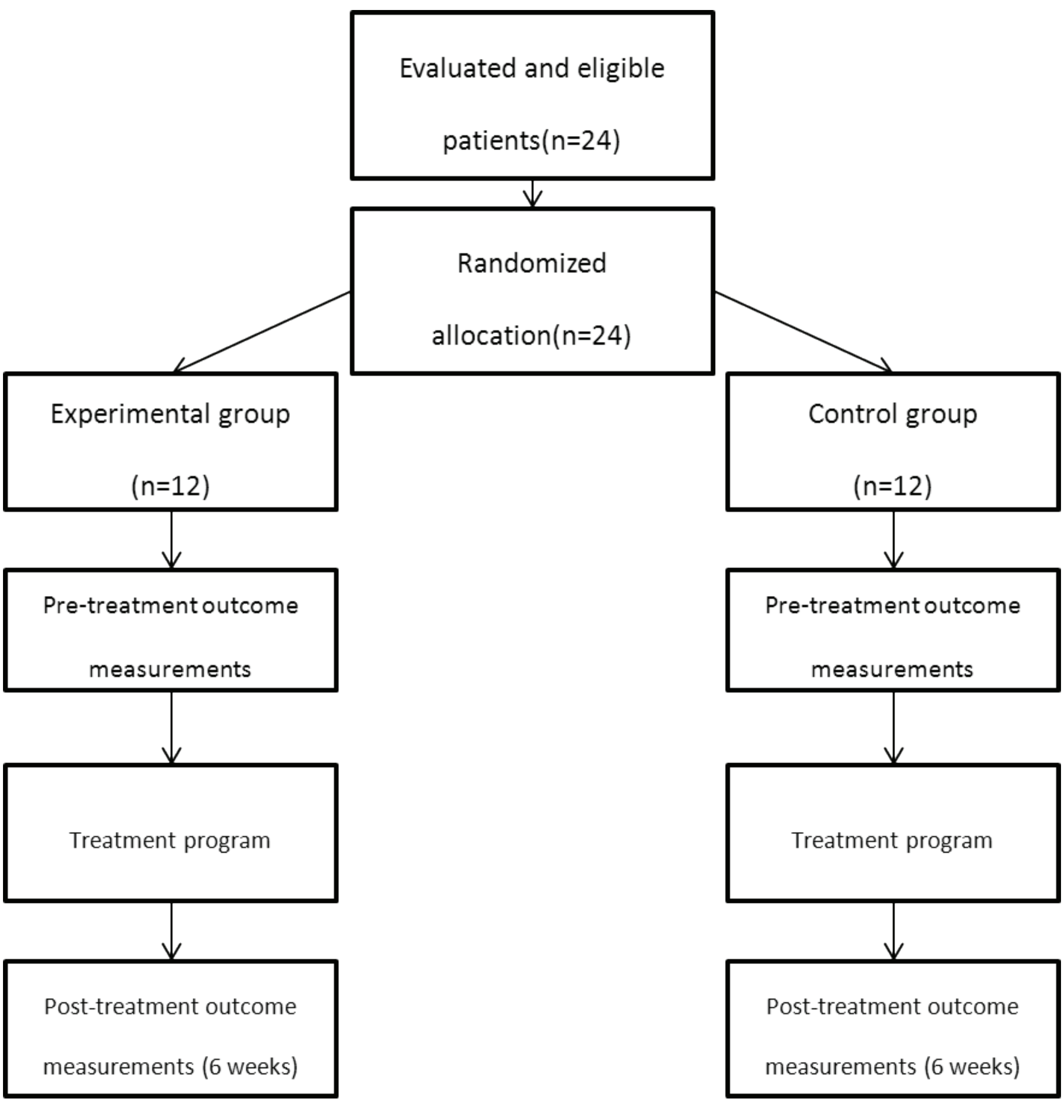

Figure 1: Flow diagram of the study

offset of electromyographic activity) was determined by the observational method by 2 expert physical therapists and was presented according to percent of phase duration [26]. Row electromyographic signals in each activity time window, rectified and low pass filtered and then root mean square (RMS) of muscle activity were calculated [26,27]. Amplitude was normalized according to peak magnitude [28]. All electromyographic data were processed by MATLAB software and averaged over six trials.

All data were normally distributed according to Sapiro-Wilk statistical test. The paired t - test was used to compare the mean difference of variables in each group and independent t-test was used to compare the mean difference of variables between the two groups. All statistical analysis was performed with SPSS (Windows, version 11.0), with an alpha level of 0.05.

Results

The means of the quantitative variables including age, height, weight, time since stroke, BBS and NIHSS in both groups are presented in the Table1. The results of the *t* independent statistical test demonstrated that the differences between the groups were not significant for age (P>0.48), height (P>0.45), weight (P>0.61), time since stroke (P>0.53), BBS (P>0.63) and NIHSS (P>0.31).

No significant differences in pre-treatment measurements were found between two groups.

Within group comparisons showed that in the experimental group, the symmetry ratio improved after the termination of the treatment (P=0. 001)(See Table 2). In the stance phase, only the RMS of electromyographic activity of the paretic GM increased significantly (P=0.005). There were no significant changes in the other parameters during the stance phase. In the swing phase only the activity duration of paretic RF decreased significantly (P=0.004). In the control group, symmetry ratio improved after the treatment period, but was not statistically significant.

No electromyographic parameters changed significantly in the stance phases. In the swing phase only the activity duration of non-paretic RF decreased significantly (P=0.02) .)(See Tables 3 and 4).

Discussion

Amplitude and Duration of Gastrocnemius Medialis (GM) Activity During Gait Cycle

Plantar flexor muscles have an important role in supporting the body's centre of mass (COM) during the stance phase [28]. Following stroke, severe weakness of these muscles causes inability to support body's COM and the generation of sufficient power for leg propulsion in early swing [28]. This leads to the development of compensatory mechanisms and changes in timing and activity levels of plantar flexors and other lower extremity muscles in both limbs [28]. Plantar flexors tend to show long duration and low amplitude activity during the swing phase in order to compensate for their insufficiency [1,28]. It should be noted that under normal conditions,

Table 2: Weight bearing symmetry ratios for two groups before and after treatment

	Experimental group			Control group		
	Before treatment	**After treatment**	**P value**	**Before treatment**	**After treatment**	**P value**
Symmetry Ratio	1.6(0.13)	1.22(0.07)	0.001*	1.57(0.13)	1.54(0.11)	0.09

Symmetry ratio of 1.0 reflects a 50/50 weight bearing.

Table 3: Amplitude and duration of activity of lower extremity muscles in stance phase in each group before and after treatment and between two groups after treatment.

Parameters	**Experimental group**			**Control group**			**Between groups comparison**
	before	**after**	**P value**	**before**	**after**	**P value**	**P value**
P GM Amp	0.235(0.45)	0.8(0.75)	0.005*	0.34(0.52)	0.393(0.51)	0.9	0.03*
NP GM Amp	0.69(0.6)	0.723(0.61)	0.6	0.627(0.58)	0.652(0.5)	0.8	0.23
P TA Amp	0.523(0.54)	0.624(0.71)	0.5	0.601(0.61)	0.567(0.49)	0.6	0.56
NP TA Amp	0.674(0.67)	0.696(0.7)	0.9	0.753(0.68)	0.756(0.67)	0.9	0.73
P RF Amp	0.55(0.5)	0.633(0.51)	0.6	0.536(0.56)	0.564(0.53)	0.9	0.81
NP RF Amp	0.561(0.43)	0.65(0.6)	0.5	0.756(0.46)	0.674(0.6)	0.7	0.57
P BF Amp	0.45(0.43)	0.543(0.55)	0.3	0.455(0.61)	0.523(0.65)	0.5	0.48
NP BF Amp	0.432(44)	0.505(0.48)	0.4	0.543(0.52)	0.563(0.53)	0.9	0.76
P GM Dur	53.24(42.26)	71.53(74.46)	0.1	65.23(67.12)	69.43(65.45)	0.6	0.33
NP GM Dur	74.11(64.22)	74.05(67.4)	0.9	81.23(79.52)	79.42(73.12)	0.8	0.81
P TA Dur	65.34(71.23)	63.26(73.23)	0.8	73.23(75.71)	71.56(67.34)	0.4	0.61
NP TA Dur	73.25(63.38)	71.45(74.5)	0.7	81.64(76.33)	84.55(74.43)	0.5	0.69
P RF Dur	85.23(89.34)	86.45(86.49)	0.8	81.82(76.34)	86.23(79.33)	0.6	0.55
NP RF Dur	87.21(86.62)	91.61(93.13)	0.6	84.41(81.23)	89.51(83.81)	0.5	0.9
P BF Dur	81.47(73.12)	82.09(83.23)	0.8	76.83(77.11)	81.56(78.59)	0.4	0.41
NP BF Dur	75.3(66.03)	86.33(81.4)	0.3	79.31(75.56)	85.44(81.56)	0.4	0.82

Values are mean (S.D.) †Amplitude of activity is according to mV and duration of activity is according to percent of stance phase duration. ‡ Abbreviations: P: paretic; NP: Non-paretic; Amp: Amplitude; Dur: Duration; GM; Gastrocnemius Medial; TA: Tibialis Anterior; RF: Rectus Femoris; BF: Biceps Femoris

Table 4: Amplitude and duration of activity of lower extremity muscles in swing phase in each group before and after treatment and between two groups after treatment.

Parameters	Experimental group			Control group			Between groups comparison
	Before	After	P value	Before	After	P value	P value
P GM Amp	0.134(0.17)	0.149(0.16)	0.4	0.12(0.15)	0.128(0.15)	0.8	0.93
NP GM Amp	0.213(0.21)	0.221(0.18)	0.6	0.243(0.15)	0.165(0.16)	0.06	0.25
P TA Amp	0.196(0.19)	0.282(0.27)	0.3	0.142(0.25)	0.221(0.18)	0.07	0.1
NP TA Amp	0.255(0.15)	0.198(0.21)	0.4	0.211(0.19)	0.256(0.21)	0.3	0.5
P RF Amp	0.127(0.13)	0.181(0.15)	0.3	0.131(0.15)	0.159(0.12)	0.6	0.3
NP RF Amp	0.139(0.11)	0.151(0.15)	0.8	0.157(0.2)	0.209(0.9)	0.4	0.3
P BF Amp	0.123(0.19)	0.115(0.151)	0.6	0.112(0.11)	0.131(0.14)	0.5	0.8
NP BF Amp	0.165(0.19)	0.182(0.15)	0.7	0.172(0.16)	0.201(0.19)	0.6	0.8
P GM Dur	22.1(21.11)	12.78(12.92)	0.3	11.23(12.54)	15.11(12.56)	0.3	0.2
NP GM Dur	28.12(21.31)	33.15(23.76)	0.7	32.54(25.2)	32.1(25.55)	0.8	0.9
P TA Dur	31.7(33.23)	27.54(20.23)	0.9	29.63(23.17)	33.17(24.12)	0.2	0.8
NP TA Dur	41.23(23.13)	34.56(21.67)	0.1	31.7(26.9)	40.1(21.67)	0.1	0.8
P RF Dur	42.23(21.43)	23.17(19.65)	0.004*	37.44(21.8)	31.12(23.5)	0.4	0.1
NP RF Dur	41.12(21.56)	45.66(29.8)	0.6	46.77(23.45)	32.66(24.12)	0.02*	0.2
P BF Dur	31.22(23.44)	34.23(27.16)	0.7	34.12(21.56)	29.16(19.76)	0.5	0.47
NP BF Dur	38.34(21.33)	42.13(28.65)	0.6	41.22(23.44)	45.12(21.72)	0.7	0.32

Values are mean (S.D.) †Amplitude of activity is according to mV and duration of activity is according to percent of phase duration. ‡ Abbreviations: P: paretic; NP: Non-paretic; Amp: Amplitude; Dur: Duration; GM; Gastrocnemius Medial; TA: Tibialis Anterior; RF: Rectus Femoris; BF: Biceps Femoris

these muscles do not exhibit significant activity during the swing phase [28,29]. Following the intervention in the experimental group, electromyographic activity of paretic GM increased in stance phase. This might increase the GM's ability to control and support body's COM. The role and the importance of compelling weight bearing via a shoe lift, employed in the experimental group, might logically explain any differences related to the increased electromyographic activity of paretic GM muscle in patients in the experimental group.

It is also necessary to discuss the roles of somatosensory afferents, especially load afferents on the amount of activity of plantar flexor muscles [10]. Somatosensory afferents are integrated in order to produce appropriate motor responses. This information is used in the structure of internal models to produce varied movements and also for the correction of movement errors [10,30,31]. Following neurologic conditions such as stroke, somatosensory deafferentation occurs [32]. Nielsen showed that after eliminating plantar flexor muscle afferents, their electromyographic activity decreased [30]. He indicates that the activity of these muscles is dependent on the integration of all synaptic inputs to motor neurons innervating these muscles [30]. Eliminating 10 percent of the amount of afferent inputs leads to a decrease of about 50 percent of electromyographic activity of plantar flexor muscles [30].

Nielsen explains that the role of afferent signals to produce proper motor responses is important. These signals are used by central controllers to correct movement errors and modify motor strategies [30]. Following studies regarding GM postural responses in normal and body immersion conditions, Dietz et al. explained that the activity of GM muscle is mainly controlled by proprioceptive inputs [10]. They indicated that the activity of leg extensor muscles is related to load receptor afferent inputs. Indeed, Golgi tendon organ and Ib afferents of leg extensors are responsible for creating different patterns of electromyographic activity of these muscles during gait [10,33]. Bastiaanse et al. showed the dependency of electromyographic activity of antigravity muscles, especially GM to the amount of weight bearing during different phases of gait cycle [34]. One possibility is that following an asymmetric weight bearing in hemiparetic patients, load receptors of paretic lower limb are deprived from normal load and this may decrease electromyographic activity of plantar flexors. On the other hand, in the intact lower limb that tolerates more body weight, electromyographic activity of plantar flexors increase. Results of different studies have indicated an increase of electromyographic activity of the plantar flexors in the non-paretic side [7,28]. In this study, compelled weight bearing on the paretic side may, through balancing load on either limb and thereby correcting somatosensory deafferentation, affect the plantar flexor activity in stance phase. In the control group, despite prescribing 6 weeks of physical therapy, electromyographic activity of GM in both limbs did not change. Activity duration of paretic and non-paretic GM did not change in stance and swing phases of the gait cycle in either group after treatment. It seems that any change in activity duration of muscles, is dependent on the strategies adopted by the central nervous system.

Amplitude and Duration of Tibialis Anterior Activity During Gait Cycle

Following a stroke, electromyographic activity of the paretic TA decreases in all phases of the gait cycle. Increased activity duration of TA in stance phase is due to the inability of plantar flexor muscles to produce enough force. Adopting this strategy by the patient leads to fatigue. On the other hand, activity duration of TA increases in the swing phase, which is an adaptive strategy due to the inability of this muscle to produce enough force for toe clearance. In the non-paretic limb, electromyographic activity does not change in any phases of the gait cycle, but activity duration increases in phases in which the muscle is active [1,7,28]. Neither group post-treatment demonstrated electromyographic activity changes of the TA. Dietz et al. indicated that dorsal flexor muscles are mostly controlled by central mechanisms. In other words, dorsal flexor muscle have a stronger correlation with supraspinal motor control centres than plantar flexor muscle do. Thus, cortical control of dorsal flexor muscles is more prominent [35]. For this reason, we conclude that compelled weight bearing on the paretic side via shoe lift cannot change the activity of TA. In healthy people, TA activity increases in swing phase to prevent toe contact with the ground [29]. Increased activity of TA was not seen in either of the groups after treatment. This might be due to the fact that in both treatment approaches in this study, central motor control areas employed other patterns of muscular activity such as increasing hip flexor muscle activity for toe clearance [29]. TA activity duration did not change in 2 phases of gait cycle after treatment in both groups. We propose that the duration and intensity of treatment be modified in the future studies.

Amplitude and Duration of Rectus Femoris Activity During Gait Cycle

Following a stroke, electromyographic activity of paretic RF muscle decreases in all phases of the gait cycle. To compensate for this decrease, adaptive strategies occur in both limbs [7,28,29]. According to Den otter, RF activity duration in both limbs increases in stance phase for stabilizing knee joints. Due to the inability of paretic RF to produce sufficient force in the beginning of the swing phase, activity duration of this muscle increases. This is also observable in non-paretic limb because of compensation [1]. In this study, we expected physical therapy to increase electromyographic activity of paretic RF in both groups. However, it was not seen even in experimental group in which compelled weight bearing on the paretic side was employed in all daily activities. Lamontagne explains that Ib afferents of plantar flexor muscles increase the activity of muscles around knee joints indirectly via spinal pathway thereby increasing knee joint stability [7]. However, this effect was not seen in the present study. According to Nadeou, since the weakness of proximal muscles is less than that of the distal muscles, proximal muscles may resist against any changes induced by intervention [36]. Following both treatment approaches, activity duration of paretic RF in the experimental group and non-paretic RF in the control group decreased. Decreased activity duration of RF in swing phase is considered as an improved effect after treatment and indicates a modification of motor control strategies after treatment in both groups. In this case, the role of physical therapy seems to be remarkable.

Amplitude and Duration of Biceps Femoris Activity During Gait Cycle

Following a stroke, severe weakness of paretic BF and the inability to support the body's centre of mass in stance phase, activity duration of BF increases in paretic limb and with a lesser degree in non-paretic limb. Activity duration of BF also increases in stance phase, which is a compensatory strategy to support the body's centre of mass and to maintain dynamic stability during gait. The electromyographic activity of paretic BF decreases in all phases of gait cycle [5,37]. After treatment, electromyographic activity of BF in niether limbs changed in either groups. Pauvert explains that in afferent feedbacks from Golgi tendon organs of the GM muscular facilitate the activity of BF muscle during gait; however, we found that in the experimental group, electromyographic activity did not change. This may be explained by the fact that indirect facilitating pathway from Ib afferents of plantar flexor muscles to biceps femoris may be impaired after stroke. Activity duration of BF muscles did not change after treatment in either group. We recommend the modification of both treatment programs, specially in the experimental group and recording electromyographic activity of other lower limb muscles.

Conclusion

The results of the current study indicated that compelled weight bearing on the paretic limb via a shoe lift, increased activity of some paretic limb muscles which are load dependent. A major limitation of this study was the lack of findings on the relationship between changes in EMG activity during gait and gait biomechanics, energy expenditure and functional measures of gait and balance. Future studies regarding the modification of this treatment program are essential.

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References

1. Den Otter AR, Geurts AC, Mulder T, Duysens J. Abnormalities in the temporal patterning of lower extremity muscle activity in hemiparetic gait. Gait Posture. 2007;25(3):342-52.
2. Den Otter AR, Geurts AC, Mulder T, Duysens J. Gait recovery is not associated with changes in the temporal patterning of muscle activity during treadmill walking in patients with post-stroke hemiparesis. Clin Neurophysiol. 2006;117(1):4-15.
3. Patterson KK, Nadkarni NK, Black SE, McIlroy WE. Gait symmetry and velocity differ in their relationship to age. Gait Posture. 2012;35(4):590-4.
4. Patterson KK, Gage WH, Brooks D, Black SE, McIlroy WE. Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. Gait Posture. 2010;31(2):241-6.
5. Knutsson E, Richards C. Different types of disturbed motor control in gait of hemiparetic patients. Brain. 1979;102(2):405-30.
6. Shiavi R, Bugle HJ, Limbird T. Electromyographic gait assessment, Part 2: Preliminary assessment of hemiparetic synergy patterns. J Rehabil Res Dev. 1987;24(2):24-30.
7. Lamontagne A, Stephenson JL, Fung J. Physiological evaluation of gait disturbances post stroke. Clin Neurophysiol. 2007;118(4):717-29.
8. Ricamato AL, Hidler JM. Quantification of the dynamic properties of EMG patterns during gait. J Electromyogr Kinesiol.

2005;15(4):384-92.
9. Patterson KK, Parafianowicz I, Danells CJ, Closson V, Verrier MC, Staines WR, et al. Gait asymmetry in community-ambulating stroke survivors. Arch Phys Med Rehabil. 2008;89(2):304-10.
10. Dietz V, Duysens J. Significance of load receptor input during locomotion: a review. Gait Posture. 2000;11(2):102-10.
11. Dietz V. Evidence for a load receptor contribution to the control of posture and locomotion. Neurosci Biobehav Rev. 1998;22(4):495-9.
12. Kamphuis JF, de Kam D, Geurts AC, Weerdesteyn V. Is weight-bearing asymmetry associated with postural instability after stroke? A systematic review. Stroke Res Treat.2013:692137.
13. Aruin AS, Rao N, Sharma A, Chaudhuri G. Compelled body weight shift approach in rehabilitation of individuals with chronic stroke. Top Stroke Rehabil. 2012;19(6):556-63.
14. Siebers A, Oberg U, Skargren E. The effect of modified constraint-induced movement therapy on spasticity and motor function of the affected arm in patients with chronic stroke. Physiother Can. 2010;62(4):388-96.
15. Reiss AP, Wolf SL, Hammel EA, McLeod EL, Williams EA. Constraint-Induced Movement Therapy (CIMT): Current Perspectives and Future Directions. Stroke Res Treat.2012:159391.
16. Rodriguez GM, Aruin AS. The effect of shoe wedges and lifts on symmetry of stance and weight bearing in hemiparetic individuals. Arch Phys Med Rehabil. 2002;83(4):478-82.
17. Ganesan M, Lee YJ, Aruin AS. The effect of lateral or medial wedges on control of postural sway in standing. Gait Posture. 2014;39(3):899-903.
18. Mohapatra S, Eviota AC, Ringquist KL, Muthukrishnan SR, Aruin AS. Compelled Body Weight Shift Technique to Facilitate Rehabilitation of Individuals with Acute Stroke. ISRN Rehabil. 2012.328018.
19. Berg K, Wood-Dauphinee S, Williams JI. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. Scand J Rehabil Med. 1995;27(1):27-36.
20. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther. 1987;67(2):206-7.
21. Mansfield A, Danells CJ, Inness E, Mochizuki G, McIlroy WE. Between-limb synchronization for control of standing balance in individuals with stroke. Clin Biomech (Bristol, Avon). 2011;26(3):312-7.
22. Chaudhuri S, Aruin AS. The effect of shoe lifts on static and dynamic postural control in individuals with hemiparesis. Arch Phys Med Rehabil. 2000;81(11):1498-503.
23. Frigo C, Crenna P. Multichannel SEMG in clinical gait analysis: a review and state-of-the-art. Clin Biomech (Bristol, Avon). 2009;24(3):236-45.
24. Davies PM. Steps to follow. 2 ed; Springer 2000: 236-65.
25. Vearrier LA, Langan J, Shumway-Cook A, Woollacott M. An intensive massed practice approach to retraining balance post-stroke. Gait Posture. 2005;22(2):154-63.
26. Raez MB, Hussain MS, Mohd-Yasin F. Techniques of EMG signal analysis: detection, processing, classification and applications. Biol Proced Online. 2006;8:11-35.
27. Hwang IS, Lee HM, Cherng RJ, Chen JJ. Electromyographic analysis of locomotion for healthy and hemiparetic subjects--study of performance variability and rail effect on treadmill. Gait Posture. 2003;18(1):1-12.
28. Higginson JS, Zajac FE, Neptune RR, Kautz SA, Delp SL. Muscle contributions to support during gait in an individual with post-stroke hemiparesis. J Biomech. 2006;39(10):1769-77.
29. Peat M, Dubo HI, Winter DA, Quanbury AO, Steinke T, Grahame R. Electromyographic temporal analysis of gait: hemiplegic locomotion. Arch Phys Med Rehabil. 1976;57(9):421-5.
30. Nielsen JB, Sinkjaer T. Afferent feedback in the control of human gait. J Electromyogr Kinesiol. 2002;12(3):213-7.
31. Grey MJ, Mazzaro N, Nielsen JB, Sinkjaer T. Ankle extensor proprioceptors contribute to the enhancement of the soleus EMG during the stance phase of human walking. Can J Physiol Pharmacol. 2004;82(8-9):610-6.
32. Mazzaro N, Nielsen JF, Grey MJ, Sinkjaer T. Decreased contribution from afferent feedback to the soleus muscle during walking in patients with spastic stroke. J Stroke Cerebrovasc Dis. 2007;16(4):135-44.
33. Dietz V, Colombo G. Effects of body immersion on postural adjustments to voluntary arm movements in humans: role of load receptor input. J Physiol. 1996;497(3):849-56.
34. Bastiaanse CM, Duysens J, Dietz V. Modulation of cutaneous reflexes by load receptor input during human walking. Exp Brain Res. 2000;135(2):189-98.
35. Dietz V, Gollhofer A, Kleiber M, Trippel M. Regulation of bipedal stance: dependency on "load" receptors. Exp Brain Res. 1992;89(1):229-31.
36. Nadeau S, Gravel D, Arsenault AB, Bourbonnais D. Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. Clinical Biomechanics. 1999;14:125-35.
37. Parvataneni K, Olney SJ, Brouwer B. Changes in muscle group work associated with changes in gait speed of persons with stroke. Clin Biomech (Bristol, Avon). 2007;22(7):813-20.