Relationship between lower extremity muscle strength and dynamic balance in people post-stroke

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Key words: *cerebrovascular accident, postural control, muscle strength.*

Summary. *The purpose of this study was to determine how lower extremity muscle weakness is related to post-stroke difficulties in balancing.*

Methods. Dynamic balance of 30 people post-stroke and 30 neurologically sound people was assessed by the Functional Reach Test and the Timed Up and Go Test. Bilateral lower extremity muscle strength was measured in classical manual muscle testing positions using a Lafayette instrument.

Results. There was a weak correlation between lower extremity muscle strength and the Functional Reach Test: from r=0.05 to r=0.53 for the impaired extremity and from r=0.23 to r=0.53 for the sound extremity. Control group results were from r=0.51 to r=0.86. The correlation between lower extremity muscle strength and the Timed Up and Go Test was from r=−0.33 to r=−0.64 for the impaired extremity and from r=−0.35 to r=−0.58 for the sound extremity. Control group results in this testing situation were from r=−0.63 to r=−0.90.

Conclusion. The results of the study indicate that the loss of lower extremity muscle strength as a result of cerebrovascular accident has a poor influence on dynamic balance problems in people post-stroke.

Introduction

Research reveals that many factors, such as timing and force scaling problems, sensory loss, abnormal muscle tone, loss of sensory and anticipatory postural control, also secondary post-store factors, such as muscle shortening, muscle atrophy, limitations of range of motion, and biomechanical alignment contribute to the difficulties of dynamic balancing in post-stroke population (1-3). This study concentrated only on the impact of the main sign of cerebrovascular accident (CVA) − decreased or lost ability to generate muscle contraction force and its relationship with dynamic balance.

Concepts about the correlation between dynamic balance and muscle strength in post-stroke patients are contradictory. Bobath (4) and Davies (5) claim that regaining trunk muscle control to enhance dynamic balance is the key point of CVA rehabilitation.

However, recent research confirms that trunk muscles control is relatively intact after unilateral hemisphere lesions. Carr and Shepherd's (6) electromyography (EMG) results revealed bilateral responses in axial muscles (rectus abdominis), but only contralateral responses in upper extremities. Dickstein et al. (7) obtained similar results. EMG study of concentric and eccentric contractions of rectus abdominis and lumbar erector spinae muscles (in 41 survivors of unilateral thromboembolic CVA in anterior brain circulation and 20 neurologically non-impaired controls) showed synchronization between EMG records of bilateral axial muscles, indicating a common drive simultaneously subserving bilateral motor neuron pools. No statistically significant difference was found between the results of people post-stroke and the control group. Dickstein et al. (7) presents a challenging theoretical idea: in the case of bilateral trunk muscle innervation, people with unilateral strokes might have deterioration in the activation of trunk muscles on both the contralateral and the ipsilateral body side. However, no studies are available to deny or support this idea.

According to Carr & Shepherd (6) it is lower extremity muscles that control the movements of trunk over the base of support. The decreased trunk movements seen as a person post-stroke reaches out in sitting, reflects a reluctance to move the body mass too far towards the periphery of the base of support because of insecurity that results from difficulty stabilizing the lower extremity.

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The investigated research hypothesis was that lower extremity strength of people post-stroke correlated strong with dynamic standing balance, sit-stand transitions and walking.

Material and methods

Data was gathered at the Pacific University, Forest Grove, Oregon, USA in 2001 and in Kaunas University of Medicine Hospital in 2002. The project was in accordance with ethical standards on human experiments of Helsinki Declaration of 1975 (as revised in 1983).

Thirty-three people post-stroke served as subjects. Thirty neurologically sound people corresponding the post-stroke group by age and gender served as a control group. Of the post-stroke volunteers who met the selection criteria, three were excluded because of their inability to lie prone for muscle strength testing procedure or severe ataxia. The selection criteria included:

1. Cerebrovascular accident happened in the pool of the middle or anterior artery;
2. To be able to perceive and follow the directions;
3. To be able to walk for 10 meters unassisted (subjects could use their customary walking aid and brace);
4. To be able to stand for at least one minute unassisted and without a walking aid
5. To have no orthopedic problems affecting lower extremities;
6. To have at least 90 degrees of nonparetic shoulder motion.

The subjects in the both groups were between the ages of 49 and 89 (X=70.6; S=9.7). The sample included 18 women and 12 men in each group. Post-stroke subjects had experienced cerebrovascular accident between 14 and 180 months ago (X=59.0; S=48.0). Thirteen post-stroke subjects had right hemiparesis and 17 had left hemiparesis. Twenty-three post-stroke subjects used a walking aid, 8 used ankle brace during the testing procedures. None of the control group subjects used any compensatory aid.

All the tests were performed in the order described.

The Timed Up and Go Test was used to test the time needed for subjects to get from a chair (seat height 46 cm), walk a distance of 3 meters, turn, walk back and sit down on the chair at a comfortable speed. The time was measured in seconds using a stopwatch from the moment of giving the command to start (subjects sitting with their back against the chair) until the moment the subject sat down on the chair with their back against the chair. Subjects were allowed to use their customary walking aid. No physical assistance was given, though the tester was guarding the subjects in case of loss of balance. Subjects performed one practice trial prior the test trial.

The Functional Reach Test was used to measure the maximum distance that subjects could reach forward horizontally beyond arm's length while maintaining a fixed base of support in standing with comfortable stance width. Subjects were not allowed to use any assistive device. Subjects reached with their nonparetic arm parallel to a tape measure fixed to a wall at the height of their acromion. The fingers were flexed, making a fist. The distance moved by the third metacarpal from the start position to the position at the end of the reach was measured in centimeters. No attempt was made to control the subjects' method of reach. The upper extremity was not allowed to contact the wall during the reach. If the subject touched the wall or took a step during testing, the trial was repeated. Subjects performed one practice trial prior to two test trials. The scores of the two test trials were averaged. The tester guarded the subjects in case of loss of balance.

Bilateral lower extremity strength was tested in classical manual muscle testing positions (supine, prone and sitting), using a Lafayette instrument (Lafayette Instrument Corp., USA). The Lafayette instrument placement was according to Daubney and Culham (8), Andrews et al. (9) and Bohannon (10), since they have reported validity and reliability. The tester stabilized the dynamometer load manually to ensure an isometric test. The test was performed on the nonparetic lower extremity first. Subjects performed one practice trial prior to three test trials for each of the 10 lower extremity movements tested. Each trial lasted 4-5 seconds to allow the subjects to generate their maximum available force. A 30 second break followed every trial. The average of three test trials was scored.

For the statistical analysis of data Spearman's correlation and t-test were used. The data or the difference between the groups was considered to be statistically significant at $p<0.05$. All the statistics was performed using statistical package "SPSS-10".

Results

The was no statistically significant difference between the strength of right and left lower extremity in the control group, so the measurements of the right extremity were used for the further comparisons.

As it was expected, post-stroke survivors' sound extremity was statistically significantly stronger than the impaired one. Nevertheless, in the comparison with the control group both post-stoke survivors' extremities generated a significantly lower power. The force values for the impaired extremity were 37.4-87.0% lower than the values for the control group extremity and the forces values for the sound extremity were 8.8-41.7% lower than the values for the control group extremity. There was no statistically significant difference between the groups only for the strength of hip extensors. The averages of the lower extremity muscle strength are presented in Figure 1.

Post-stroke group performed significantly worse than the control group in the Functional Reach Test and the Timed Up and Go Test. The averages of the results are presented in the Figure 2 and Figure 3.

Table presents Spearman's correlation between lower extremity muscle performance and the Functional Reach Test and the Timed Up and Go Test. Post-stroke group data showed no correlation (r=0.05) to weak (r=0.53) correlation between the Functional Reach Test results and the strength of separate muscles of lower extremity. The highest correlation was between the Functional Reach Test results and the force produced by the sound extremity ankle invertors (r=0.53) and knee extensors (r=0.50). The highest correlation between the Functional Reach Test results and muscle force in the impaired extremity was for knee extension (r=0.57) and hip flexion (r=0.45). There was a strong correlation between the control group's lower extremity muscle strength and the Functional Reach Test (from r=0.51 to r=0.86). The correlation was statistically significantly different between post-stroke and control group, except for the sound ankle inversion and eversion. It is interesting to notice that the correlation between the Functional Reach Test results and hip extension, as well as knee flexion was not statistically significant both on sound extremity and impaired one.

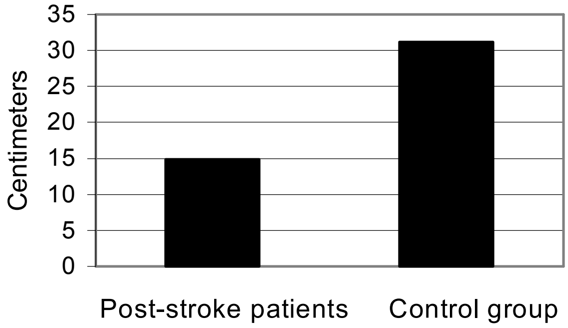

Fig. 2. **The Functional Reach Test results**

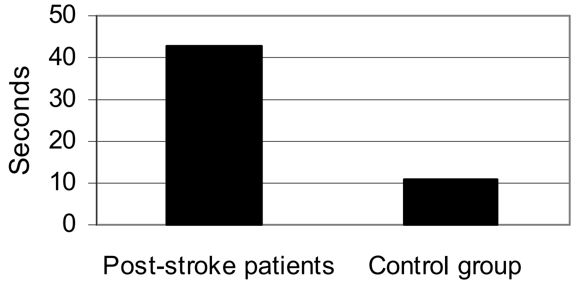

Fig. 3. **The Timed Up and Go Test results**

Correlation between the Timed Up and Go Test results and lower extremity muscle strength was from weak (r=-0.33) to fair (r=-0.64). The highest correlation between the Timed Up and Go Test results and the strength of sound lower extremity was on the

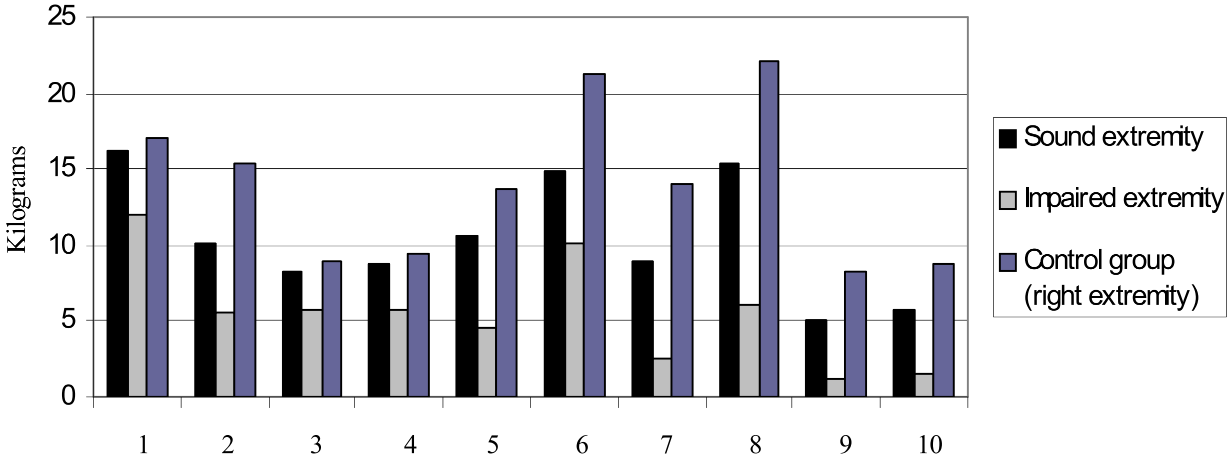

Fig. 1. **Lower extremity muscle strength**

1 – hip flexion; 2 – hip extension; 3 – hip adduction; 4 – hip abduction; 5 – knee flextion; 6 – knee extension; 7 – ankle dorsiflexion; 8 – ankle plantarflexion; 9 – ankle eversion; 10 – ankle inversion.

***Table.* Spearman's Correlation Coefficients (r): the Functional Reach Test and the strength of lower extremity muscle groups. The Timed Up and Go Test and the strength of lower extremity muscle groups**

Low extremities movements	Functional Reach Test	Timed Up and Go Test
Hip flexion:		
Sound	r = 0.44*	r = –0.52*
Impared	r = 0.45*	r = –0.64*
Control group (right)	r = 0.80*	r = –0.86*
Hip extension:		
Sound	r = 0.34	r = –0.44*
Impared	r = 0.30	r = –0.33*
Control group (right)	r = 0.80*	r = –0.90*
Hip adduction:		
Sound	r = 0.47*	r = –0.47*
Impared	r = 0.39*	r = –0.44*
Control group (right)	r = 0.83*	r = –0.86*
Hip abduction:		
Sound	r = 0.30	r = –0.35*
Impared	r = 0.32*	r = –0.52*
Control group (right)	r = 0.72*	r = –0.83*
Knee flexion:		
Sound	r = 0.23	r = –0.39*
Impared	r = 0.05	r = –0.46*
Control group (right)	r = 0.70*	r = –0.81*
Knee extension:		
Sound	r = 0.50*	r = –0.57*
Impared	r = 0.57*	r = –0.52*
Control group (right)	r = 0.82*	r = –0.89*
Ankle dorsiflexion:		
Sound	r = 0.44*	r = –0.58*
Impared	r = 0.06	r = –0.46*
Control group (right)	r = 0.86*	r = –0.87*
Ankle plantarflexion::		
Sound	r = 0.33	r = –0.42*
Impared	r = 0.38*	r = –0.57*
Control group (right)	r = 0.84*	r = –0.88*
Ankle inversion:		
Sound	r = 0.53*	r = –0.57*
Impared	r = 0.07	r = –0.40*
Control group (right)	r = 0.51*	r = –0.63*
Ankle eversion:		
Sound	r = 0.45*	r = –0.45*
Impared	r = 0.10	r = –0.42*
Control group (right)	r = 0.59*	r = –0.63*

*Statistically significant (at $p<0.05$).

same muscle groups as it was in the Functional Reach Test results: ankle dorsiflexion (r=-0.58) and ankle inversion (r=-0.57). The highest correlation between the Timed Up and Go Test results and impaired lower extremity was for hip flexion (r=-0.64) and ankle plantarflexion (r=-0.57). Control group data showed a strong correlation between the lower extremity muscle strength and the Timed Up and Go Test (from r=-0.63 to r=-0.90). Correlation between post-stroke and control groups differed statistically significantly.

Discussion

The data demonstrated that post-stoke people's mean ability to balance while reaching forward was 53% of that of healthy elderly individuals. Similar results are presented by Dunkan et al (11) and Giorgetti et al (12). As an average they required 5 times longer time to perform the Timed Up and Go Test in the comparison with healthy elderly individuals (18). This is in comparison with Podsiadlo& Richardson (13) results.

The results of the study show that people post-stroke experience muscle strength weakness or loss not only in the lower extremity contralateral to the impaired hemisphere, but in the ipsilateral, too. This might be an outcome of post-stroke hypomobility or it might as well serve as an evidence for the existence of ipsilateral activation of extremities, which is impaired by cerebrovascular accident in one of the hemispheres.

Correlation between dynamic balance tests results and the lower extremity muscle strength measures obtained in this study were comparable to the outcomes of the previous research of post-stroke people (14-17). The relationship between dynamic balance, which was assessed using the Functional Reach Test and the Timed Up and Go Test, and lower extremity muscle strength in post-stroke people was weak. However, the correlation in neurologically intact people was strong.

Hamrin et al. (18) also reported a weak correlation between post-stroke people lower extremity muscle strength and balance when tested on balance platform (from r=0.28 to r=0.53). Bohannon study of subjects post-stroke (15) demonstrated fair correlation (r=0.78) between gait performance, categorized according to the assistance needed to walk over 150 feet and the strength of hip flexors in both of the extremities. Bohannon & Walsh (17) reported a fair correlation (r=0.67) between comfortable gait speed and the strength of impaired extremity knee extensors of people post-stroke and also a fair correlation (r=0.74) with the strength of knee extensors of the sound lower extremity. Research of post-stroke and healthy people show slightly stronger relationships between lower extremity muscle strength and walking performance than with dynamic standing balance (18-20).

Even though plantarflexors are considered to play a dominant role in the locomotion in healthy (8, 21) and post-stroke subjects (16, 20) the results of our study demonstrated a fairly weak correlation between balancing in walking and the plantarflexors strength of the impaired extremity (r=-0.57). It is comparable to of Nadeau et al. (14) study of post-stroke population, that demonstrated low correlation between bilateral plantarflexor strength and the Timed Up and Go Test performance (for impaired extremity r=-0.43, for healthy extremity r=-0,30).

Weak correlation obtained in this study leads to the conclusion, that apparently individuals can produce the same level of balance by using different strategies, which might include compensations within muscle groups of the impaired side as well as the compensations of the sound extremity. It also means that factors other than strength affect balance. Using post-stroke subjects, Karlsson & Fryberg (22) reported good correlation between balance and proprioception (r=0.74), between balance and muscle tone (r=0.69) and fair correlation between balance and somatosensory integration (r=0.55). Alterations of postural adjustments, reduction of selective movements, muscular incoordination, biomechanical misalignments, secondary muscular disorders, visual and vestibular impairments, pain and psychosocial issues have been previously described in people post-stroke (1, 4-6, 17, 22-24). All of these problems could affect, separately or in combination balance and should be considered in order to explain the weak relationship between muscle strength and balance.

Brown et al. (24) analyzed ambulation abilities of healthy but frail elderly people and found a stronger correlation (r=-0.74) between standing up from a 14-inch chair and the strength of hip, knee extensors and ankle plantarflexors than the correlation between gait speed (r=0.62) and the strength of the same muscles. They concluded that the relationship between muscle strength and gait is weak due to low walking speeds. Olney et al. (16) study of people post-stroke provided evidence that the greater the gait speed, the greater the relationship between gait and the strength of ankle plantarflexors, hip and knee flexors. The correlation was higher on the impaired side.

The fact that subjects were walking at their comfortable speed – not at maximum available speed – while performing the Timed Up and Go Test could partly explain the low correlation found in our study.

Moreover, there was a discrepancy between the subjects' attempts to perform in different testing procedures: submaximal efforts in the Timed Up and Go Test and maximal available isometric muscle contraction in lower extremity muscle strength testing.

Weak correlation between the Functional Reach Test and lower extremity muscle strength obtained in our study might be partly explained by the fact that no measures were taken to control the subjects' strategy of reaching forward. The authors observed that a few subjects used hip strategy and, despite having weaker lower extremities, did better on the Functional Reach Test than the ones who had relatively stronger lower extremity muscles and used ankle strategy. However, this observation was not measured or systematically documented, so drawing any significant conclusions is limited.

Another factor that might have had contributed to decreasing the level of the relationship between the muscle strength and dynamic balance, is the assessment of the strength of isolated muscle groups, instead of assessing synergistic muscle groups. Keenan et al. (25) demonstrated that due to impairment of voluntary control, individuals post-stroke produce less power under isolated movement testing conditions than in functional activity situations. In addition, muscle strength in our study was tested in lying, which excluded motor control aspects, such as feed-forward postural adjustments and anticipatory postural adjustments, and biomechanical aspects, such as interaction of active and passive forces, that is required for adequate force generation in functional activity, such as standing.

The study results might also have been impacted by the variability in both subjects' age and in time past the onset of stroke. However, according to Keenan et al. (25) study, age of the subjects and time past the onset of the stroke did not demonstrate a significant effect on balance reactions; neither did gender.

Finally, it is unknown what balance test assesses what aspect of postural control. There are a variety of balance assessment tools, but as research shows, the scores on the assessments bear little relationship to each other, in both the healthy and post-stroke populations (11, 22, 23). Thus, the weak correlation between lower extremity muscle strength and dynamic balance, which was assessed by the Functional Reach Test and the Timed Up and Go Test, should not be generalized for the balance assessments of post-stroke population. Further research on balance assessment tools, in order to find the aspects of balance they are testing, might show interesting results in the terms of relationship with lower extremity muscle strength.

Conclusions

1. Survivors of cerebrovascular accident experience force production problems both in the contralateral and ipsilateral to the impaired hemisphere lower extremity.
2. Weakness or loss of lower extremity muscle strength as a result of cerebrovascular accident has a poor influence on dynamic balance problems in people post-stroke.
3. Post-stoke dynamic balance problems can not be solved by using only lower extremity muscle strength building means.

Ryšys tarp patyrusiųjų galvos smegenų infarktą apatinių galūnių raumenų jėgos ir dinaminės pusiausvyros

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Raktažodžiai: galvos smegenų infarktas, pusiausvyros valdymas, raumenų jėga.

Santrauka. Šio darbo tikslas – nustatyti, kaip patyrusių galvos smegenų infarktą žmonių apatinių galūnių raumenų silpnumas susijęs su dinamine pusiausvyra.

Metodai. Tyrime dalyvavo 30 galvos smegenų infarktą patyrusių žmonių. Kontrolinę grupę sudarė 30 neurologinių sutrikimų neturinčių žmonių. Jų dinaminė pusiausvyra buvo tiriama „Funkcinio siekimo“, „Stotis ir eiti“ testais. Abipusė apatinių galūnių raumenų jėga buvo matuojama įprastinėse raumenų testavimo padėtyse naudojant Lafayette aparatą.

Rezultatai. Koreliacija tarp patyrusiųjų galvos smegenų infarktą apatinių galūnių raumenų jėgos ir „Funkcinio siekimo“ testo rezultatų buvo nuo r=0,05 iki r=0,53 pažeistos galūnės ir nuo r=0,23 iki r=0,53 sveikos galūnės. Kontrolinės grupės rezultatai: nuo r=0,51 iki r=0,86. Koreliacija tarp patyrusiųjų galvos smegenų infarktą apatinių galūnių raumenų jėgos ir „Stotis ir eiti“ testo rezultatų buvo nuo r=−0,33 iki r=−0,64 pažeistos galūnės ir nuo r=−0,35 iki r=−0,58 sveikos galūnės. Kontrolinės grupės rezultatai buvo nuo r=−0,63 iki r=−0,90.

Išvada. Šio tyrimo duomenimis, smegenų infarktą patyrusių žmonių apatinių galūnių raumenų jėgos susilpnėjimas arba jos praradimas menkai daro įtaką sveikos pusės dinaminės pusiausvyros sutrikimams, kurių atsiranda po galvos smegenų infarkto.

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References

1. Shumway-Cook A, Woollacott MH. Motor control. Theory and practical applications. 1st ed. Baltimore: Lippincott Williams & Wilkins; 1995.
2. Horak FB, Henry SM, Shumway-Cook A. Postural perturbations: new insights for treatment of balance disorders. Phys Ther 1997;77:517-32.
3. Bloem BR, Allum JHJ, Carpenter MG, Honegger F. Effects of proprioceptive loss on postural control. Gait Posture 1998;8:214-42.
4. Bobath B. Adult hemiplegia: evaluation and treatment. 2nd ed. Oxford: Butterworth/heinemann; 1990.
5. Davies PM. Right in the middle: selective trunk activity in the treatment of adult hemiplegia. 2nd ed. Berlin; New York: Springer-Verlag; 1990.
6. Carr J, Shepherd R. Movement science. Foundations for physical therapy in rehabilitation. 2nd ed. Gaithersburg, Maryland: An Aspen Publication; 2000.
7. Dickstein R, Heffes Y, Laufer Y, Ben-Haim Z. Activation of selected trunk muscles during symmetric functional activities in poststroke hemiparetic and hemiplegic patients. J Neurol Neurosurg Psychiatry 1999;66:218-21.
8. Daubney ME, Culham EG. Lower-extremity muscle force and balance performance in adults aged 65 years and older. Phys Ther 1999;79:1177-85.
9. Andrews AW, Thomas MW, Bohannon RW. Nominative values for isometric muscle force measurements obtained with hand-held dynamometers. Phys Ther 1996;76:248-59.
10. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. Phys Ther 1986;66:206-9.
11. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. J Gerontol 1990;45: M192-M197.
12. Giorgetti MM, Harris BA, Jette A. Reliability of clinical balance outcome measures in the elderly. Physiother Res Int 1998;3:274-83.
13. Podsiadlo D, Richardson S. The timed “UP and GO”: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39:142-8.
14. Nadeau S, Gravel D, Arsensault AB, Bourbonnais D, Goyette M. Dynamometric assessment of the plantarflexors in hemiparetic subject: relations between muscular, gait and clinical parameters. Scand J Rehabil Med 1997;29:137-46.
15. Bohannon RW. Standing balance, lower extremity muscle strength, and walking performance of patients referred for physical therapy. Percept Mot Skills 1995;80:379-85.
16. Olney SJ, Griffin MP, Monga TN, McBride I. Work and power in gait of stroke patients. Arch Phys Med Rehabil 1991;7 2:309-14.
17. Bohannon RW, Walsh S. Nature, reliability, and predictive value of muscle performance measures in patients with hemiparesis following stroke. Arch Phys Med Rehabil 1992; 73:721-5.
18. Hamrin E, Eklund G, Hillgren AK, Borges O, Hall J, Hellstrom O. Muscle strength and balance in post-stroke patients. Upsala J Med Sci 1982;87:11-26.
19. Danneskiold-Samsoe B, Kofod V, Munter J, Grimby G, Schnohr P, Jensen G. Muscle strength and functional capacity in 78-81-year-old men and women. Eur J Appl Physiol 1984; 52:310-4.
20. 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. Clin Biomech 1999;14:125-35.
21. Wolfson L, Judge J, Whipple R, King M. Strength is a major factor in balance, gait, and the occurrence of falls. J Gerontol 1995;50A:64-7.
22. Karlsson A, Frykberg G. Correlation between force plate measures for assessment of balance. Clin Biomech 2000;15: 365-9.
23. Ringsberg K, Gerdhem P, Johansson J, Obrant KJ. Is there a relationship between balance, gait performance and muscular strength in 75-year-old women? Age Ageing 1999;28:289-93.
24. Brown M, Sinacore DR, Host HH. The relationship of strength to function in the older adult. J Gerontol 1995;50A: 55-9.
25. Keenan MA, Perry J, Jordan C. Factors affecting balance and ambulation following stroke. Clin Orthop 1984;182:165-76.

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