

Lower-Extremity Strength Differences Predict Activity Limitations in People With Chronic Stroke

Patricia Kluding, Byron Gajewski

Background. Body system impairments following stroke have a complex relationship with functional activities. Although gait and balance deficits are well-documented in people after stroke, the overlapping influence of body impairments makes it difficult to prioritize interventions.

Objective. This study examined the relationship between prospectively selected measures of body function and structure (body mass index, muscle strength, sensation, and cognition) and activity (gait speed, gait endurance, and functional balance) in people with chronic stroke.

Design. This was a cross-sectional, observational study.

Methods. Twenty-six individuals with mean (SD) age of 57.6 (11) years and time after stroke of 45.4 (43) months participated. Four variables (body mass index, muscle strength difference between the lower extremities, sensation difference between the lower extremities, and Mini-Mental Status Exam score) were entered into linear regression models for gait speed, Six-Minute Walk Test distance, and Berg Balance Scale score.

Results. Lower-extremity strength difference was a significant individual predictor for gait speed, gait endurance, and functional balance. Cognition significantly predicted only gait speed.

Limitations. The authors did not include all possible factors in the model that may have influenced gait and balance in these individuals.

Conclusions. Strength deficits in the hemiparetic lower extremity should be an important target for clinical interventions to improve function in people with chronic stroke.

P Kluding, PT, PhD, is Assistant Professor, Department of Physical Therapy and Rehabilitation Science, School of Allied Health, University of Kansas Medical Center, 3056 Robinson Hall, Mailstop 2002, 3901 Rainbow Blvd, Kansas City, KS 66160 (USA). Address all correspondence to Dr Kluding at: pkcluding@kumc.edu.

B Gajewski, PhD, is Associate Professor, Department of Biostatistics, Schools of Medicine and Nursing, University of Kansas Medical Center.

[Kluding P, Gajewski B. Lower-extremity strength differences predict activity limitations in people with chronic stroke. *Phys Ther*. 2009;89:73-81.]

© 2009 American Physical Therapy Association



Post a Rapid Response or
find The Bottom Line:
www.ptjournal.org

The consequences of stroke can be understood in the context of the *International Classification of Functioning, Disability and Health* (ICF) model.^{1,2} In this model, *health condition* represents both healthy body systems and disorders or disease. This concept includes the damage that occurs in the brain tissue as a result of an ischemic blockage or hemorrhagic stroke, as well as other comorbidities. This damage often affects performance at the level of *body function and structures* in the ICF model, including motor weakness in a hemiparetic pattern, hypertonicity, impaired motor control, sensory loss, decreased cognition, and the effects of deconditioning.³ Together, these problems in body function and structures interact to produce problems with execution of tasks, classified as *activity* in the ICF model. Activities such as walking and functional balance ability influence a person's *participation* or ability to partake fully in life situations in the complete environment.¹

Mobility is one of the subdomains of activity and participation in the ICF model that is of specific concern to physical therapists.¹ Gait deficits in people who have had a stroke are well-documented and include both decreased walking speed^{4,5} and decreased walking endurance.⁶ Standing balance also can be affected by a stroke and may influence functional mobility and increase the risk for falling.⁷ The overlapping influence of impairments in different body systems following a stroke makes it difficult to identify interventions and determine the prognosis for improvements in function. Previous research has examined the influence of various impairments on gait speed, gait endurance, and balance in people with chronic stroke, as summarized below.

Gait speed has been found to be a strong determinant of community

mobility. One study showed that 39.5% of people living at home after a stroke were not able to walk to shopping venues or other places of interest in the community,⁴ and gait speed has been found to discriminate among self-reported levels of community ambulation.^{4,5} Several researchers⁸⁻¹¹ have found correlations among measures of muscle strength (force-generating capacity), balance, daily ambulatory activity, aerobic fitness, hypertonicity, and lower-extremity motor control with short-distance (7-10 m) walking speed in people who have survived a stroke. Regression models have identified several variables that may explain the amount of variation in gait speed in people with stroke. These factors include muscle strength of individual muscle groups in the paretic limb,¹²⁻¹⁴ muscle power of the nonparetic knee extensors,¹² sensation,¹⁴ self-efficacy,¹³ and sex.¹³

The Six-Minute Walk Test (6MWT) is a standardized test of walking endurance that can be used as a test of submaximal exercise capacity in people with stroke.⁶ Reference equations for 6MWT distance in elderly people who are healthy have been established based on sex, body mass index (BMI), and age.^{15,16} In people with stroke, predictive factors include knee extension strength of the paretic leg, hypertonicity, balance, fast-paced gait speed, and aerobic fitness.^{9,17,18} Measures of strength in other muscle groups, level of motor recovery, sensation, or cognition have not been reported in a regression model for prediction of 6MWT distance in people with stroke.

In addition to impaired gait mobility, people may have decreased functional balance following a stroke, as measured by the Berg Balance Scale (BBS).¹⁹⁻²¹ Measurements of walking speed, aerobic fitness, daily ambulatory activity, and cognitive status have been found to correlate with

BBS scores in people with chronic stroke.^{7,10} Some researchers have evaluated BBS scores in a regression analysis as a potential predictor for falls or gait function,^{7,10} but limited information is available on what factors may predict BBS score as an indicator of functional balance.

These studies have consistently found that individual measures of lower-extremity strength are important predictors of function following stroke, although a measure of overall hemiparetic leg weakness in comparison with the strong side has not been evaluated. There is some evidence that measures of general strength deficits in the lower limb are more closely related to functional outcome than measures of individual muscle function,²²⁻²⁴ although none of these studies used regression analysis.

Furthermore, although there is some indication that BMI, sensation, and cognition may be important, these measures have not been assessed as potential predictors of function in people with stroke. It is important to identify which impairments in body function and structures are the strongest contributors to functional loss for people with chronic stroke in order to provide an appropriately targeted intervention. Although formal rehabilitation, in our current health care system, commonly ends after the first few months following a stroke, recent research has indicated that intense practice opportunities (eg, several hours per day for 2 weeks) can induce functional recovery²⁵⁻²⁹ and can even induce neural changes in people who had a stroke years previously.³⁰ The purpose of this study was to examine the relationship between prospectively selected measures of body function and structure (BMI, muscle strength, sensation, and cognition) and activity (gait speed, gait endurance, and functional balance) in people with

Table 1.
Participant Characteristics and Activity-Level Measures^a

Participant No.	Age (y)	Time Since Stroke (mo)	Sex	Affected Side of Body	MMSE Score	6MWT Distance (m)	10-m Walk Time (s)	BBS Score
1	56	11	Male	Left	26	160	21	28
2	63	36	Male	Right		159	39	34
3	68	36	Male	Right	18	152	24	44
4	45	28	Female	Right	27	221	14	54
5	50	12	Male	Right	26	91	22	35
6	55	10	Male	Left		259	12	49
7	55	32	Male	Right	14	64	48	33
8	79	52	Male	Right	23			43
9	58	168	Female	Right	23	137	32	
10	54	32	Male	Left	28	100	25	
11	70	31	Female	Left	18	9	60	7
12	52	58	Male	Right	21	244	13	48
13	52	140	Female	Right	24	259	16	45
14	73	16	Female	Left	27	85	30	20
15	34	20	Female	Left	29	344	9	53
16	36	45	Female	Left	30	219	14	52
17	63	16	Female	Right	25	116	24	50
18	47	15	Female	Left	30	107	21	44
19	70	40	Female	Right	25	479	7	51
20	58	11	Male	Right	18	570	6	55
21	50	28	Female	Left	29	104	26	44
22	64	108	Male	Right	25	213	13	36
23	57	18	Male	Left	27	183	14	47
24	75	48	Male	Left	27	76	20	42
25	56	132	Female	Left	29	351	9	53
26	58	38	Male	Left	30	358	8	54
Mean (SD)	57.6 (11)	45.4 (42.8)			24.96 (4.4)	202.4 (134.3)	21.1 (13.1)	42.5 (11.8)

^a MMSE=Mini-Mental Status Exam, 6MWT distance=distance covered during the Six-Minute Walk Test, BBS=Berg Balance Scale.

chronic stroke. We hypothesized that differences in these body function and structure measurements would predict measurements of activity in a linear regression model.

Method

An institutionally approved informed consent form was signed by all individuals prior to their participation in this study. All testing was performed in a single session for each participant, with rests provided during the testing as requested by the participants.

Participants

A convenience sample of 26 people with chronic stroke was recruited for this study from a local stroke support organization. Volunteers were included in this study if they had a chronic stroke (at least 6 months prior to the study) and were able to transfer from a sitting position to a standing position and walk 9.1 m (30 ft) without assistance. A description of participant characteristics (54% male, 50% right-side stroke) and activity-level measurements are provided in Table 1.

Body Function and Structure Measurements

Four measures of body function or structure were prospectively selected to be included in the regression model as potential predictors of gait and balance function: (1) BMI, (2) difference in muscle strength between the lower extremities, (3) difference in sensation between the lower extremities, and (4) cognition. These measures were selected because, although previous research^{7,12-15} suggests that these

Table 2. Summary of Muscle Strength Testing Procedures Using a Handheld Dynamometer and Reliability Correlation Coefficients (N=26)

Muscle Group	Testing Position	Dynamometer Placement	Reliability Coefficient ^a
Hip flexors	Sitting, knees at 90° of flexion, shank vertical to floor, thigh raised 10° off seat	Front thigh just proximal to knee joint	Less-affected side: .93 More-affected side: .98
Knee extensors	Sitting, hips and knees at 90° of flexion, shank vertical to floor, heel slightly off floor	Anterior shank just proximal to ankle	Less-affected side: .94 More-affected side: .98
Knee flexors	Sitting, hips and knees at 90° of flexion, shank vertical to floor, heel slightly off floor	Posterior shank just proximal to ankle	Less-affected side: .85 More-affected side: .98
Ankle dorsiflexors	Sitting, hips and knees at 90° of flexion, shank vertical to floor, heel touching floor	Dorsal surface of the foot, proximal to the first metatarsophalangeal joint	Less-affected side: .95 More-affected side: .98
Hip abductors	Supine, hips and knees straight and in neutral rotation	Lateral aspect of thigh proximal to knee joint	Less-affected side: .97 More-affected side: .94

^a Intraclass correlation coefficient (3,1) was used to calculate reliability of 2 strength measurements.

may be important variables, they have not been fully investigated with prediction models in people with stroke.

BMI. Body weight (in pounds) was measured using a portable scale, and height (in inches) was measured using a tape measure taped to a wall. Pounds and inches were converted to kilograms and meters. Body mass index was calculated using the equation: $\text{weight (kg)} / [\text{height (m)}]^2$.³¹

Muscle strength. Five major muscle groups in the bilateral lower extremities were tested using a handheld dynamometer (MicroFET*): hip flexors, hip abductors, knee flexors, knee extensors, and ankle dorsiflexors. The force pad of the dynamometer was held perpendicular to the limb segment, and participants were instructed to push against the dynamometer with maximal force for a count of 5. The desired movement was demonstrated to the participants, and their understanding was confirmed before starting. The less-affected lower limb was tested first, followed by the more-affected limb. Each muscle group was tested twice, and the average was used for analysis. Reliability for this type of

dynamometer has been established previously,^{32,33} but we assessed the test-retest reliability for these individuals with stroke using our procedures. Each participant was tested twice within each session, with a short rest between tests. One primary tester (PK) performed the majority of strength tests, and she was assisted by 2 other physical therapists. The testing position, dynamometer placement, and reliability coefficient (intraclass correlation coefficient [3,1])³⁴ for each muscle group tested are described in Table 2. A composite strength score for each lower extremity was calculated by adding together strength values for hip flexion, hip abduction, knee extension, knee flexion, and ankle dorsiflexion for each extremity.^{35,36} The composite value for the more-affected side was subtracted from

that of the less-affected side to give an indication of the difference in strength between the 2 sides.

Sensation. A 5.07/10-g Semmes-Weinstein monofilament was used to test sensation in both distal lower extremities.^{37,38} Each participant was positioned supine with shoes and socks removed. A practice trial was given to the participant on the upper extremity of the less-involved side to instruct the participant in the expected sensation. With eyes closed, the participant was instructed to respond "yes" when he or she felt the monofilament pressure on the plantar surface of the foot. Pressure was applied until the filament bent slightly for 2 seconds for a total of 10 repetitions on each foot, alternating between the least-calloused plantar aspect of the first and fifth metatarsals.

Table 3. Descriptive Statistics of Independent Variables^a

Measure	BMI (kg/m ²)	Strength Difference (kg)	Sensation Difference	MMSE
Mean	28.96	67.92	2.88	24.96
SD	6.6	59.3	3.2	4.4
Minimum	18.2	-26.5	0	14
Maximum	45.1	235.4	10	30
n	26	26	25	24

* Hoggan Health Industries, 8020 S 1300 West, West Jordan, UT 84088.

^a BMI=body mass index, MMSE=Mini-Mental Status Exam.

The number of correct responses on each foot was recorded. The difference in sensation between the 2 sides also was calculated by subtracting the number of correct responses out of 10 for the more-affected side from that of the less-affected side. A sensation difference score of 0 indicates no difference between the sides, and a larger number indicates a greater difference.

Cognition. The Folstein Mini-Mental Status Exam (MMSE) was administered to each participant.³⁹ The MMSE is a general screen for dementia and tests orientation, memory, attention, language, and ability to follow instructions. The highest possible score is 30.

Activity Measurements

Three measures of functional mobility were used, as described below.

Gait speed. Self-selected walking speed was measured by having the participants walk at a comfortable pace over a 10-m distance. Participants were permitted to use any assistive devices or orthoses they preferred. Time (in seconds) was measured with a stopwatch, and the average time for 2 trials was recorded.

Gait endurance. The 6MWT was used as a measure of walking endurance, using a 30.48-m (100-ft) walkway. Participants were instructed to cover as much ground as possible during the 6 minutes and were permitted to stop and rest, if needed. They were permitted to use their typical assistive devices or orthoses. Standardized encouragement (eg, "You are doing well, keep up the good work.") was provided to each participant at 1-minute intervals. If the participant requested a rest, the timer was not stopped during the rest, and standardized statements (eg, "It has been ___ minutes. Rest as long as you need to, and let me know when we can get started again.")

were read to the participant. Total distance walked (in meters) was recorded.

Functional balance. The BBS was used as a measure of balance.¹⁹ On the BBS, performance of each of 14 items, ranging in difficulty from sitting unsupported to standing on one foot, is rated on a 4-point scale, for a maximum possible score of 56.

Data Analysis

We used SPSS 15.0 for Windows[†] for analysis of all data. Histograms for each variable were analyzed for normal distributions, and scatterplots were analyzed for outlying scores. Correlations among variables were calculated with the Pearson correlation coefficient. Linear regression models with 4 predictors (BMI, strength difference, sensation difference, and MMSE) were calculated for 10-m walk time, 6MWT distance, and BBS scores. The validity of each model was assessed through analysis of colinearity statistics (variance inflation factor) and Q-Q plots of unstandardized residuals, as well as Cook's distance (influence points) values for each participant. Data for participants with any missing data were not entered into the regression analysis (case deletion). A .05 level of significance was used for all statistical tests.

Role of the Funding Source

This study was not funded.

Results

Descriptive Statistics and Correlations

Twenty-one of the 26 participants completed all of the testing. Five participants did not complete the full assessment because of time constraints, and only the values of the tests that were completed were entered into the analysis. The values for

each of the independent variables are presented in Table 3. Significant correlations were noted among several of the variables, as noted in Table 4. With regard to the relationship between activity limitations and body function impairments, gait speed (10-m walk time) was significantly correlated with strength difference and MMSE, gait endurance (6MWT distance) was significantly correlated with strength difference, and balance (BBS) was significantly correlated with strength difference.

Gait Speed

The result of the linear regression model for the 10-m walk time with 4 variables (BMI, strength difference, sensation difference, and MMSE) was statistically significant, with strength difference and MMSE score as significant individual factors. The sensation difference variable approached significance ($P=.06$) in this model. The result of this model is presented in Table 5.

Gait Endurance

The linear regression model for the 6MWT distance with 4 variables (BMI, strength difference, sensation difference, and MMSE) was not significant, but strength difference was significant as an independent factor (Tab. 5).

Functional Balance

The linear regression model for the BBS score with 4 variables (BMI, strength difference, sensation difference, and MMSE) approached significance ($P=.06$), with strength difference as a significant independent factor. Difference in sensation did approach significance in this model ($P=.06$).

Discussion and Conclusions

The difference in strength between the lower extremities and mental status (MMSE) were found to be significantly correlated to gait speed (10-m walk time), and both factors were

[†] SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

Predicting Activity Limitations in Chronic Stroke

Table 4.
Pearson Correlation Among Variables^a

Variable	BMI (kg/m ²)	Strength Difference (kg)	Sensation Difference	MMSE Score	10-m Walk Time (s)	6MWT Distance (m)	BBS Score
BMI	1.00						
Strength difference	.20	1.00					
Sensation difference	-.30	.09	1.00				
MMSE score	.08	-.12	-.09	1.00			
10-m walk distance	.22	.50 ^b	-.10	-.51 ^b	1.00		
6MWT distance	-.19	-.48 ^b	.07	.06	-.74 ^c	1.00	
BBS score	-.12	-.51 ^c	.18	.34	-.83 ^c	.67 ^c	1.00

^a BMI=body mass index, MMSE=Mini-Mental Status Exam, 6MWT=Six-Minute Walk Test, BBS=Berg Balance Scale.

^b $p \leq .05$.

^c $p \leq .01$.

significant individual predictors of gait speed in our regression model. The relationship between lower-extremity strength and gait speed is supported by previous studies that examined this relationship with the strength and power of individual muscle groups.¹²⁻¹⁴ In these studies, strength or power of the paretic knee extensors,^{12,13} hip flexors and plantar flexors,¹⁴ and the nonparetic knee extensors¹² were found to predict gait speed in people with stroke. The different muscles identified in each of these studies may be partially explained by the strong relationship in weakness among muscle groups in an individual participant. The likely correlation among strength val-

ues for individual muscle groups may have influenced the regression models. Furthermore, none of these previous studies used values that indicated the magnitude of interlimb differences in muscle strength. Our study showed that a single measure that was intended to capture the weakness in the entire lower limb compared with the nonparetic lower extremity was a strong independent predictor of gait speed after stroke.

The influence of mental status (MMSE) on gait speed has not been reported previously for people with stroke. However, various measures of mental status (ie, the MMSE, a depression symptom score, and mea-

sures of positive and negative affect and mood) have been found to predict 6MWT distance in elder people who were healthy.^{40,41} Our study included participants with a wide range of MMSE scores, with several of the participants scoring below 24, which indicates risk of dementia⁴² but which also may have been due to the presence of aphasia. We are fairly confident that even participants with low MMSE scores were able to follow the very simple instructions for the gait speed tests (ie, walk at a comfortable pace). The MMSE is used primarily as a screening measure for dementia, and its usefulness to ascertain overall mental status is limited. Furthermore, the

Table 5.

Adjusted R^2 Values for Gait Speed (10-m Walk Distance), Gait Endurance (Six-Minute Walk Test [6MWT] Score), and Balance (Berg Balance Scale [BBS] Score) and Weights (B), Probability Values, and Confidence Intervals (CI) for Significant Predictors of Body Mass Index (BMI), Strength Difference, Sensation Difference, and Mini-Mental Status Exam Score

Measure	10-m Walk Time			6MWT Distance			BBS Score		
Adjusted R^2	.442			.085			.261		
F	5.36			1.51			2.85		
P	.01			.24			.06		
Independent Variable	B	P	CI	B	P	CI	B	P	CI
BMI	0.1	.38		-0.5	.45		0.2	.31	
Strength difference	0.1	.01	0.02, 0.2	-1.1	.02	-2.1, -0.1	-0.1	.01	-0.2, -0.01
Sensation difference	-1.2	.06		6.44	.26		1.3	.06	
MMSE score	-1.4	.005	-2.4, -0.4	-0.001	.5		0.7	.11	

difficulty in distinguishing cognitive deficits from communication deficits in this population may complicate the interpretation of our findings. Future work should screen for aphasia and include more-comprehensive cognitive and psychological assessments to determine the true nature of the relationship between gait speed and mental status in people with stroke.

The difference in strength between the lower extremities was found to be significantly correlated with gait endurance (6MWT distance). Although the overall regression model for gait endurance was not significant, a 1-sided test was used to assess the individual predictors, which revealed a significant relationship for strength difference. Previous researchers^{9,17} have found paretic knee extension strength to be a significant predictor in regression models of gait endurance in people with stroke. Improvements in motor recovery (Fugl-Meyer test score) also have been found to predict improvements in gait endurance over a 3-month period in people who are higher functioning following subacute stroke.⁴³

The strength difference between the lower extremities correlated with balance (BBS) and was found to be a significant individual predictor for BBS score. The difference in lower-extremity sensation approached significance as a predictor of functional balance as well as gait speed. However, the sensation variable did not demonstrate strong or significant correlations with any of these measures. The influence of sensation and strength on predicting BBS score in people with stroke has not been reported previously.

Our model included 4 independent variables that we hypothesized would influence gait and balance function in people with chronic stroke. Two

of these independent variables (sensation and strength) were calculated by taking the difference in scores between the 2 lower limbs. An advantage of this difference score is that it may be a valid marker for the construct of hemiparetic severity. This between-limb comparison provides unique insight, as compared with other studies (eg, Pohl et al⁴³) that have utilized single-limb measures (such as Fugl-Meyer test scores) as an indication of hemiparetic severity after stroke. These single-limb scores do not allow for any comparison between sides. One limitation of this approach is the difficulty interpreting this score, as a lower difference score could mean that both limbs were equally weak or lacking in sensation.

Several different methods have been reported in the literature for the calculation of strength deficit scores.^{22,24,44} Measurements of strength difference expressed as a percentage of body weight have been found to be valid,⁴⁴ although no change in correlation was apparent when comparing strength measurements normalized and not normalized to body weight.²² Other strategies have been used to express strength difference as a ratio or percentage of the strong side or of predicted normal reference values.^{22,24,44} However, when values are expressed as ratios or percentages, an appreciation of the absolute numbers is lost. For example, a 10% difference could mean any range of values, depending on the baseline strength. The simple subtraction measure used in our study to describe strength deficit is similar to that used in the study by Pohl et al⁴⁵ to calculate "cost" in comparing 2 different conditions.

In calculating the total strength score of each limb, we did not include hip extension because of the difficulty obtaining a standard position for testing hip extension with

the handheld dynamometer. Although other researchers also have excluded hip extension from calculation of composite leg strength scores,³⁶ certainly the inclusion of hip extension might influence the relationship of these scores to functional tasks. Another limitation of our study is that we did not include factors in our regression model that have been shown to correlate with gait and balance function in people with stroke, such as age, hypertonicity, aerobic fitness, self-efficacy, and sex.^{9,11,13,17}

We did not focus on the relationship between balance and gait in this study, although it is likely that balance has an influence on gait function, as previously reported in people with subacute and chronic stroke.^{10,43} The relationship that we found between the gait and balance measures in our participants may have influenced our regression models.

We considered 3 tasks as components of *activity* using the ICF model: gait speed, gait endurance, and functional balance. Consequently, 3 regressions were fit. Another possible approach for future work would be to expand the database so that *activity limitations* can be treated as a latent variable. This would allow a structural equation modeling framework to be used in order to promote parsimony (one dependent variable) while reducing measurement error by incorporation of 3 manifest variables. Although our study demonstrated statistical significance with several of the predictors, only moderately strong correlations were found. These suggested modifications to the analysis should further clarify the factors that predict activity limitations. A larger sample size (N=100) would be required to take advantage of such an approach. A larger data set also would allow us to include more than 4 independent

variables and test for interactions in the regression analyses.

The strong influence of the difference in lower-extremity strength on gait speed, gait endurance, and functional balance indicates that overall strength deficits in the hemiparetic lower extremity should be an important target for clinical interventions. Improvements in measures of isometric torque to make the values between the lower extremities more similar should lead to improvements in function. Several comprehensive rehabilitation approaches have been reported to improve strength of the hemiparetic lower extremity, such as home-based exercise,⁴⁶ general fitness training,^{47,48} and task-oriented exercise.⁴⁹ Investigating whether strength training alone can improve muscle strength and function would be an important area of future research. The potential impact of cognitive status on gait function also is an interesting area to explore further.

Dr Kluding provided concept/idea/research design, writing, data collection, and project management. Dr Gajewski provided consultation (including review of manuscript before submission). Both authors provided data analysis.

The authors thank the American Stroke Foundation for their assistance with recruitment and for use of their facilities for data collection.

This study was approved by the Human Subjects Committee of the University of Kansas Medical Center.

This article was received August 15, 2007, and was accepted September 14, 2008.

DOI: 10.2522/ptj.20070234

References

- World Health Organization. International Classification of Functioning, Disability and Health; 2002. Available at: <http://www.who.int/classifications/icf/en/>. Accessed February 23, 2008.
- Jette AM. Toward a common language for function, disability, and health. *Phys Ther*. 2006;86:726-734.
- Duncan PW, Zorowitz R, Bates B, et al. Management of adult stroke rehabilitation care: a clinical practice guideline. *Stroke*. 2005;36:e100-e143.
- Lord SE, McPherson K, McNaughton HK, et al. Community ambulation after stroke: how important and obtainable is it and what measures appear predictive? *Arch Phys Med Rehabil*. 2004;85:234-239.
- Perry J, Garrett M, Gronley JK, Mulroy S. Classification of walking handicap in the stroke population. *Stroke*. 1995;26:982-989.
- Eng JJ, Dawson AS, Chu KS. Submaximal exercise in persons with stroke: test-retest reliability and concurrent validity with maximal oxygen consumption. *Arch Phys Med Rehabil*. 2004;85:113-118.
- Harris JE, Eng JJ, Marigold DS, et al. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther*. 2005;85:150-158.
- Kelly JO, Kilbreath SL, Davis GM, et al. Cardiorespiratory fitness and walking ability in subacute stroke patients. *Arch Phys Med Rehabil*. 2003;84:1780-1785.
- Patterson SL, Forrester LW, Rodgers MM, et al. Determinants of walking function after stroke: differences by deficit severity. *Arch Phys Med Rehabil*. 2007;88:115-119.
- Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. *Arch Phys Med Rehabil*. 2005;86:1552-1556.
- Eng JJ, Chu KS, Dawson AS, et al. Functional walk tests in individuals with stroke: relation to perceived exertion and myocardial exertion. *Stroke*. 2002;33:756-761.
- Bohannon RW, Walsh S. Nature, reliability, and predictive value of muscle performance measures in patients with hemiparesis following stroke. *Arch Phys Med Rehabil*. 1992;73:721-725.
- LeBrasseur N, Sayers S, Ouellette M, Fielding R. Muscle impairments and behavioral factors mediate functional limitations and disability following stroke. *Phys Ther*. 2006;86:1342-1350.
- Nadeau S, Arsenault A, Gravel D, Bourbonnais D. Analysis of the clinical factors determining natural and maximal gait speeds in adults with stroke. *Am J Phys Med Rehabil*. 1999;78:123-130.
- Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. *Am J Resp Crit Care Med*. 1998;158:1384-1387.
- Poh H, Eastwood PR, Cecins NM, et al. Six-minute walk distance in healthy Singaporean adults cannot be predicted using reference equations derived from Caucasian populations. *Respirology*. 2006;11:211-216.
- Pang MYC, Eng JJ, Dawson AS. Relationship between ambulatory capacity and cardiorespiratory fitness in chronic stroke: influence of stroke-specific impairments. *Chest*. 2005;127:495-501.
- Tang A, Sibley KM, Bayley MT, et al. Do functional walk tests reflect cardiorespiratory fitness in sub-acute stroke? *J Neuro Eng Rehabil*. 2006;3:23.
- Berg K, Wood-Dauphinee SL, Williams JL. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehabil Med*. 1995;27:27-36.
- Smith PS, Hembree JA, Thompson ME. Berg Balance Scale and functional reach: determining the best clinical tool for individuals post acute stroke. *Clin Rehabil*. 2004;18:811-818.
- Mackintosh SFH, Hill K, Dodd KJ, et al. Falls and injury prevention should be part of every stroke rehabilitation plan. *Clin Rehabil*. 2005;19:441-451.
- Bohannon RW. Strength deficits also predict gait performance in patients with stroke. *Percept Mot Skills*. 1991;73:146.
- Bohannon RW, Andrews AW. Relationships between impairments in strength of limb muscle actions following stroke. *Percept Mot Skills*. 1998;87:1327-1330.
- Boissy P, Bourbonnais D, Carloti MM, et al. Maximal grip force in chronic stroke subjects and its relationship to global upper extremity function. *Clin Rehabil*. 1999;13:354-362.
- Taub E, Wolf SL. Constraint-induced movement techniques to facilitate upper extremity use in stroke patients. *Top Stroke Rehabil*. 1997;3:38-61.
- Wolf SL, Winstein CJ, Miller JP, et al. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: The EXCITE randomized clinical trial. *JAMA*. 2006;296:2095-2104.
- Macko RF, Ivey FM, Forrester LW, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. *Stroke*. 2005;36:2206-2211.
- Sullivan KJ, Knowlton BJ, Dobkin BH. Step training with body weight support: effect of treadmill speed and practice paradigms on poststroke locomotor recovery. *Arch Phys Med Rehabil*. 2002;83:683-691.
- Miller EW, Quinn ME, Seddon PG. Body weight support treadmill and overground ambulation training for two patients with chronic disability secondary to stroke. *Phys Ther*. 2002;82:53-61.
- Liepert J, Bauder H, Wolfgang HR, et al. Treatment induced cortical reorganization after stroke in humans. *Stroke*. 2000;31:1210-1216.
- Centers for Disease Control and Prevention. BMI—Body Mass Index: About BMI for Adults. Available at: http://www.cdc.gov/nccdphp/dnpa/bmi/adult_BMI/about_adult_BMI.htm. Accessed March 2, 2007.
- Li RC, Jasiewicz JM, Middleton J, et al. The development, validity, and reliability of a manual muscle testing device with integrated limb position sensors. *Arch Phys Med Rehabil*. 2006;87:411-417.
- Bohannon RW. Measuring knee extensor muscle strength. *Am J Phys Med Rehabil*. 2001;80:13-18.

- 34 Portney L, Watkins MP. *Foundations of Clinical Research: Applications to Practice*. 2nd ed, Upper Saddle River, NJ: Prentice Hall Health; 2000.
- 35 Sullivan KJ, Brown DA, Klassen T, et al. Effects of task-specific locomotor and strength training in adults who were ambulatory after stroke: results of the STEPS randomized clinical trial. *Phys Ther*. 2007;87:1580-1602.
- 36 Andrews AW, Bohannon RW. Discharge function and length of stay for patients with stroke are predicted by lower extremity muscle force on admission to rehabilitation. *Neurorehabil Neural Repair*. 2001;15:93-97.
- 37 Rahman M, Griffin SJ, Rathmann W, Wareham NJ. How should peripheral neuropathy be assessed in people with diabetes in primary care? A population-based comparison of four measures. *Diabet Med*. 2003;20:368.
- 38 Perkins BA, Zinman B, Olaleye D, Bril V. Simple screening tests for peripheral neuropathy in the diabetes clinic. *Diabet Care*. 2001;24:250.
- 39 Jackson JE, Ramsdell JW. Use of the MMSE to screen for dementia in elderly outpatients. *J Am Geriatr Soc*. 1986;36:662.
- 40 Lord SR, Menz HB. Physiologic, psychologic, and health predictors of 6-minute walk performance in older people. *Arch Phys Med Rehabil*. 2002;83:907-911.
- 41 Enright PL, McBurnie MA, Bittner V, et al. The 6-min walk test: a quick measure of functional status in elderly adults. *Chest*. 2003;123:387-398.
- 42 Brodaty H, Low LF, Gibson L, Burns K. What is the best dementia screening instrument for general practitioners to use? *Am J Geriatr Psych*. 2006;14:391-400.
- 43 Pohl PS, Perera S, Duncan PW, et al. Gains in distance walking in a 3-month follow-up post stroke: what changes? *Neurorehabil Neural Repair*. 2004;18:30.
- 44 Hsu AL, Tang PF, Jan MH. Test-retest reliability of isokinetic muscle strength of the lower extremities in patients with stroke. *Arch Phys Med Rehabil*. 2002;83:1130-1137.
- 45 Pohl PS, McDowd JM, Filion D, et al. Task switching after stroke. *Phys Ther*. 2007;87:66-76.
- 46 Duncan PW, Studenski S, Richards L, et al. Randomized clinical trial of therapeutic exercise in subacute stroke. *Stroke*. 2003;34:2173-2180.
- 47 Pang MYC, Harris JE, Eng JJ. A community-based upper-extremity group exercise program improves motor function and performance of functional activities in chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil*. 2006;87:1-9.
- 48 Teixeira-Salmela L, Olney S, Nadeau S, Brouwer B. Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. *Arch Phys Med Rehabil*. 1999;80:1211-1218.
- 49 Yang Y, Wang R, Lin K, et al. Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. *Clin Rehabil*. 2006;20:860-870.