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Muscle power, contraction velocity and functional performance after stroke

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Abstract

Objective: The goal of this study was to describe muscle function deficit in patients after stroke as well as to define the relationship between maximal muscle power (P_{max}) and optimal shortening velocity (v_{opt}) with functional efficiency in stroke survivors.

Material and Methods: A total of 134 participants were enrolled in the study, including 67 patients after a stroke and 67 volunteers, matched for age and sex (controls). Functional performance was measured with the timed Up and Go test (TUG) and additionally with Rivermead Motor Assessment (RMA) and Barthel Index (BI) in stroke survivors. To assess P_{max} and v_{opt} of the knee extensor muscles, a specially equipped Monark cycle ergometer was used.

Results: The power generated by stroke survivors was 49.6% that of their peers and muscle contraction velocity was 65.5%. P_{max}/kg and v_{opt} were associated with TUG outcomes in both groups. P_{max}/kg and v_{opt} were associated with age in the control group, but not in patients after stroke. In multivariate analysis in patients after stroke, TUG was better predicted by P_{max}/kg or v_{opt} than by the age. In stroke survivors, both P_{max}/kg and v_{opt} were related to the BI and to the RMA total results. Both BI and RMA total were not determined by age.

Conclusions: Muscle power and muscle contraction velocity in patients who have had a stroke within three months have reduced markedly. These factors significantly affect functional performance. Muscle power and optimal shortening velocity are more important determinants of functional status than age in these stroke survivors.

KEYWORDS
functional performance and age, functional performance and stroke, knee extensor muscles, muscle contraction velocity, muscle function, power measurement

1 | INTRODUCTION

Stroke is one of the leading causes of disability in older adults. One of the reasons for this is a deficit in muscle function after stroke.

From the point of view of the functional performance, maintenance of lower limb muscle mass and function seems to be crucial (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). The efficiency of the lower limbs is largely responsible for the ability to

function independently, because it allows one to stand up, maintain balance and control, and, most of all, ensure an efficient gait that is crucial for daily activities.

Muscle function can be considered in several aspects: muscle strength, muscle power and muscle contraction velocity. These parameters may in different ways determine the functional performance of patients. Muscle strength and its role in everyday functioning in patients after stroke are most often described in the literature (Bohannon, 2007; Kostka, Czernicki, Pruszyńska, & Miller, 2017). Meanwhile, some studies suggest that muscle power and muscle contraction velocity may be more important factors affecting functional efficiency than muscle strength, especially in the elderly (Bean et al., 2003; Clémençon, Hautier, Rahmani, Cornu, & Bonnefoy, 2008; Kostka, Czernicki, & Kostka, 2014). Some important activities of daily living require not only muscle strength (the ability to generate force), but also adequate power, which means the ability to generate force in a sufficiently short time (power is a product of force and velocity, Stavric & McNair, 2012).

Studies by some authors indicate a deficiency in muscle strength in patients after stroke both in the affected and unaffected side (Gerrits et al., 2009; Prado-Medeiros et al., 2012). In the limited research on deficits of muscle power after stroke, the authors compare the power deficit in relation to the unaffected side (Bohannon, 1992; Dawes et al., 2005) which does not entirely reflect the real deficit. With the exception of our preliminary study (Kostka, Fajkowska, & Miller, 2017), in the available literature we have found only one study in which the deficit of maximal muscle power in stroke survivors was compared with healthy peers (Stavric & McNair, 2012) and have not found any study on optimal muscle contraction velocity.

The goal of this study was to describe muscle function deficit in relation to peers who had not suffered a stroke. We also wanted to define the relationship between maximal muscle power (P_{max}) and optimal shortening velocity (v_{opt}) with functional efficiency in stroke survivors in a relatively short period after a cerebrovascular incident.

2 | MATERIALS AND METHODS

2.1 | Subjects

A total of 134 participants (44 women and 90 men) were enrolled in the study, including 67 patients (22 women and 45 men) who had been hospitalized after a stroke in the Neurological Rehabilitation Department of Dr. K. Jonscher Municipal Medical Centre in Lodz (patients) and 67 volunteers, matched for age and sex with group of patients, who did not suffer a stroke and were consecutively recruited during programs coordinated by the Geriatric Department of the Medical University of Lodz (controls). Inclusion criteria for post stroke survivors were as follows: time after stroke between 2 weeks and 3 months, stable clinical condition, unilateral paresis of a leg, ability to understand and execute commands, ability to perform

exercise tests, preserved walking ability (supportive equipment was allowed) and informed written consent to participate in the study. Patients with severe spasticity (>2 Ashworth scale), significant limitation of range of motion in lower limbs, severe cognitive deficits or any contraindications to exercise testing were excluded from this study.

The study was approved by the Bioethics Committee of the Medical University of Lodz.

2.2 | Protocol

All the participants underwent physical examination before the study. During the interview, information on socioeconomic status and current and previous illnesses was obtained. Anthropometric measurements (body mass and height) were also taken from all the participants and based on those measurements, body mass index (BMI) was calculated (kg/m^2).

2.3 | Functional performance

Functional performance was measured with the timed Up and Go test (TUG) in both groups. Additionally, a functional measurement specific for stroke patients - Rivermead Motor Assessment (RMA) and Barthel Index (BI) were completed for stroke survivors and used for further analyses (in the control group the "ceiling effect" was achieved in these tests). TUG (Flansbjer, Holmbäck, Downham, Patten, & Lexell, 2005; Podsiadlo & Richardson, 1991) assesses basic functions of daily life: standing up from a standard height chair, walking a short distance (3 m), returning and sitting back down. Time was measured on a stopwatch to the nearest 0.1 s. RMA (Collen, Wade, & Bradshaw, 1990; Lincoln & Leadbitter, 1979) is a widely used scale of motor function in patients after stroke. The scale consists of three sections: gross function, leg and trunk, and arm. A total score for each item ranges from 0 to 13 for RMA gross function, from 0 to 10 for RMA leg and trunk, and from 0 to 15 for RMA arm. The RMA total score was used for further analysis. BI (Collin, Wade, Davies, & Horne, 1988) is a 10-item instrument, used also in post stroke patients assessment (Wu, Wang, Teng, Huang, & Shang, 2015), measuring level of functional independence in activities of daily living. The total score ranges from 0 (minimum independence) to 20 (maximum independence).

2.4 | Muscle maximum power (P_{max}) and optimal shortening velocity (v_{opt}) measurements

To assess P_{max} and v_{opt} of the knee extensor muscles, a specially equipped Monark cycle ergometer was used as previously described (Kostka, 2005). Pedaling velocity (v), force (F) and power output (P) were calculated each 5 ms and then averaged over each downstroke period. Before the measurement, a 5-min warm-up was done by each patient. Next, the participants were asked to perform two 8 s sprints (with at least a 5-min rest between the two tests) with friction loads of 0.25 N/kg and 0.35 N/kg of body mass or less (0, 1–0,

2 N/kg) in cases where the patient had difficulty with initiating the pedaling at a given load. During the test, patients were encouraged to ride as quickly as possible. The highest value of P (P_{max}) and optimal shortening velocity (υ_{opt} – velocity at which the power reaches a maximum value) were calculated from a third-order polynomial function. P_{max} was expressed in relation to body mass [P_{max}/kg (W/kg)]. υ_{opt} was given in number of rotations per minute (rot/min).

2.5 | Statistical analysis

Data were verified for normality of distribution and equality of variances. To compare the results between the groups, a one-way analysis of variance (ANOVA), Mann-Whitney test, and chi-square test with Yates' correction for 2 × 2 tables were used. The deficits of P_{max}, υ_{opt} and TUG for patient after stroke were given as a percentage of the results obtained by the control group. To identify the quantitative variables influencing muscle power and the shortening velocity, the Pearson or Spearman correlation coefficients were used. To identify the most important determinants of functional tests, the multivariable analysis with forward selection option was made. Prior to this analysis, the data in which the distribution was not consistent with the normal data were transformed logarithmically. Data were presented as mean (±*SD*). The level of statistical significance was set at $p < 0.05$.

3 | RESULTS

Baseline characteristics of the two groups are shown in Table 1. Hemiparetic patients and the control group did not differ in regard to

TABLE 1 Participant characteristics

	Patients (n = 67)	Controls (n = 67)	p value
Age (years)	67.0 ± 9.2	66.9 ± 9.2	0.97
Height (m)	1.69 ± 0.08	1.70 ± 0.08	0.36
Body mass (kg)	77.8 ± 14.2	78.4 ± 14.8	0.72
BMI	27.3 ± 4.24	27.0 ± 3.41	0.86
Women; n (%)	22 (32.8)	22 (32.8)	1.0
Education			
Primary/vocational	30	7	<0.001
Secondary/higher	37	60	
Concomitant diseases			
Hypertension	45	37	0.21
Diabetes	22	7	0.003
Myocardial infarction	9	5	0.27
Osteoarthritis	12	29	0.002
Chronic pulmonary disease	6	6	1.00
Gastrointestinal disease	10	16	0.26

age, gender or anthropometric indices. Stroke survivors were worse educated, more often suffered from diabetes and less often suffered from osteoarthritis. Most of the patients underwent ischemic (62) and five hemorrhagic stroke.

Muscle function characteristics (P_{max}/kg, υ_{opt}) as well as TUG results and deficits in comparison with control group are shown in Table 2. Significant deficits in P_{max}/kg, υ_{opt} and TUG were observed in patients after stroke in comparison with participants from the control group both for men and women. Additionally, in post stroke patients there no sex differences in P_{max}/kg, υ_{opt} or TUG results while in control group men had higher P_{max}/kg and υ_{opt} than women.

P_{max}/kg and υ_{opt} were associated with TUG outcomes both in post stroke patients and control group participants (Table 3). Additionally, P_{max}/kg and υ_{opt} were associated with age in the control group, but not in patients after stroke. TUG was more strongly related to age in healthy adults (controls) than in stroke patients (Table 3).

In multivariate analysis with forward selection in patients after stroke, TUG was better predicted by P_{max}/kg or υ_{opt} than by the age (Table 4). In contrast, in multivariate analysis in control group, TUG was better predicted by age than by P_{max}/kg or υ_{opt} (Table 4).

Functional measurements specific for stroke patients. In functional measurements (not included in Table), the patients who had experienced a stroke obtained the following results: BI = 14.42 ± 4.33, RMA gross function = 8.51 ± 2.36, RMA arm function = 7.43 ± 4.14, RMA leg and trunk = 7.08 ± 2.39, and RMA total = 23.02 ± 7.48.

In stroke patients, both P_{max}/kg and υ_{opt} were related to the BI ($\rho = 0.48$, $p < 0.001$ for P_{max}/kg; $\rho = 0.42$, $p < 0.001$ for υ_{opt}) and to the RMA total results ($\rho = 0.58$, $p < 0.001$ for P_{max}/kg; $\rho = 0.46$, $p < 0.001$ for υ_{opt}). Both BI and RMA total were not determined by age.

Further, multivariate analysis, including the results of P_{max}/kg and age or υ_{opt} and age, was done to assess the most important determinants of BI and RMA total. For both BI and RMA total, age did not determine the variability of results.

For BI, P_{max}/kg and υ_{opt} determined 23.73% and 17.17% of the variability of results, respectively.

For RMA total, P_{max}/kg and υ_{opt} determined 32.63% and 22.69% of the variability of results, respectively.

4 | DISCUSSION

Our study investigated the range of muscle function deficits and the relationship between muscle function and functional efficiency in stroke survivors in a relatively short period after the cerebrovascular incident.

4.1 | Muscle function deficits in stroke survivors

We have shown that muscle power and muscle contraction velocity in patients who have suffered a stroke (up to three months after the incident) are significantly reduced as compared to healthy peers. The power generated by patients was only 49.6% that of the control group and muscle contraction velocity only 65.5%. In

TABLE 2 Comparison of P_{max}, υ_{opt}, and TUG results between post stroke patients and the control group

	Women				Men				All			
	Patients (n = 22)	Controls (n = 22)	% of controls	p value	Patients (n = 45)	Controls (n = 45)	% of controls	p value	Patients (n = 67)	Controls (n = 67)	% of controls	p value
P_{max}/kg	2.25 ± 0.96	3.78 ± 1.61	59.5	<0.001	2.65 ± 1.56	5.72 ± 1.80	46.3	<0.001	2.52 ± 1.39	5.08 ± 1.96	49.6	<0.001
υ_{opt}	47.3 ± 16.4	68.2 ± 17.4	69.4	<0.001	55.9 ± 19.5	87.3 ± 17.8	64.1	<0.001	53.1 ± 18.9	81.1 ± 19.8	65.5	<0.001
TUG	11.4 ± 7.9	7.6 ± 3.2	150.6	0.02	11.8 ± 7.2	6.8 ± 2.3	174.3	<0.001	11.7 ± 7.4	7.0 ± 2.6	166.0	<0.001

TABLE 3 Relationship between physical function measured with Timed Up and Go Test (TUG) and muscle function and age in post stroke patients and in the control group

	TUG	P_{max}/kg	υ_{opt}	Age
TUG		$\rho = -0.53$[a] $p < 0.001$	$\rho = -0.38$[a] $p = 0.002$	$\rho = 0.60$[a] $p < 0.001$
P_{max}/kg	$\rho = -0.64$[b] $p < 0.001$		$\rho = 0.72$[a] $p < 0.001$	$\rho = -0.44$[a] $p < 0.001$
υ_{opt}	$\rho = -0.56$[b] $p < 0.001$	$\rho = 0.81$[b] $p < 0.001$		$\rho = -0.28$[a] $p = 0.02$
Age	$\rho = 0.29$[b] $p = 0.02$	$\rho = -0.21$[b] $p = 0.09$	$\rho = -0.20$[b] $p = 0.11$	

[a]Controls. [b]Patients.

our preliminary study with power and velocity measured with the same methodology (Kostka, Fajkowska et al., 2017), we observed a slightly lower deficit for stroke patients (55.8% and 74.6% of the control group measurements for P_{max} and υ_{opt}, respectively), but patients were more diverse in terms of time after stroke (13.68 ± 36.42 months). It has been reported that some degree of spontaneous recovery can be observed sometime after stroke onset, likely by reorganization of surviving central nervous system elements (Cramer, 2008). We have found no studies on muscle power deficits in patients in the same short period after stroke and only one that included patients in a period of 4–364 days after stroke (mean 70 ± 109 days) (Bohannon, 1992). In the aforementioned study, power and velocity (measured with a different methodology) were 42.7% and 70.7% in the unaffected side, respectively. It can be expected that deficits in comparison with healthy peers would be even higher because some of the authors indicate a deficiency in muscle strength or power in patients after stroke also in the unaffected side (Prado-Medeiros et al., 2012; Stavric & McNair, 2012). For example, Stavric et al. (Stavric & McNair, 2012) reported that the knee extensor power of the control group was 35% higher than that of the affected limb of stroke survivors (at least 6 month after stroke).

In a few other articles on knee extensor muscles, power deficit after stroke was assessed in groups of patients in a later period after stroke than in our study, power measurements were made with a different methodology and separately for each leg (Hunnicutt & Gregory, 2017; Prado-Medeiros et al., 2012; Saunders, Greig, Young, & Mead, 2008; Stavric & McNair, 2012). The method of measuring the muscular power used by us involved a specially prepared ergometer that allows not only for the measurement of muscle power value, but also reflects the ability of the limbs to cooperate, as is the case during basic everyday activities such as walking or climbing stairs. In most other studies, the deficit of muscle power in affected knee extensor muscles in relation to the unaffected side is between 43% and 65% (Hunnicutt & Gregory, 2017; Prado-Medeiros et al., 2012; Stavric & McNair, 2012). However, in one study, it is only 10% (Saunders et al., 2008). This relatively small deficit found in that study probably results from the selection of participants: the study included patients who were ambulatory independent and had

TABLE 4 Multivariate analysis with forward selection for TUG test outcomes

Group	Analyzed determinants	Selected in the first step	Selected in the second step
Patients	P_{max}/kg and age	P_{max}/kg $R^2 = 43.65\%$	Age $R^2 = 47.35\%$ (age – the remaining 3.7%)
	v_{opt} and age	v_{opt} $R^2 = 30.76\%$	Age $R^2 = 36.71\%$ (age – the remaining 5.95%)
Controls	P_{max}/kg and age	Age $R^2 = 32.55\%$	P_{max}/kg $R^2 = 41.35\%$ (P_{max}/kg – the remaining 8.8%)
	v_{opt} and age	Age $R^2 = 32.55\%$	v_{opt} $R^2 = 40.95\%$ (v_{opt} – the remaining 8.4%)

completed inpatient and outpatient stroke rehabilitation. This was explained by the authors by a good neurologic recovery (Saunders et al., 2008).

We wanted to indicate the actual deficits in muscle power and muscle shortening velocity resulting only from the stroke. In our study, results obtained by stroke survivors were compared with a group of people matched for age and sex who had not suffered a stroke. Participants from our two groups did also not differ in terms of anthropometric measurements like height, body mass and BMI. We tested our patients a relatively short time after stroke (<3 months). According to Jørgensen and Jacobsen (Jørgensen & Jacobsen, 2001), lean mass of both affected and unaffected limbs decreases greatly (5%–6%) within 2 months of a stroke. Nevertheless, we were not able to eliminate the pre stroke factors affecting muscle power and muscle contraction velocity. For example, it is known that active people are characterized by better muscle function (Rantanen, Era, & Heikkinen, 1997) and, at the same time, they are less likely to have a stroke (Lee, Folsom, & Blair, 2003). That is why it is possible that stroke survivors, even before the stroke, were characterized by lower muscle power.

4.2 | Shortening velocity and functional performance

In our study, v_{opt} was correlated with all of the functional measurements, both in the stroke patients and in the control group. This parameter for the knee extensor muscles may be measured during cycling, as was done in our study (Bonnefoy, Kostka, Arsac, Berthouze, & Lacour, 1998), or during knee extension exercises (Clémençon et al., 2008). The power-velocity relationship drawn from this test allows for the calculation of the maximal power and velocity at which the power reaches a maximum value (optimal shortening velocity). This measure seems to be a very important indicator of functional performance. Clémençon et al. (2008) found that v_{opt} was an even more important determinant of functional performance in elderly women than muscle power or muscle strength. Their results described 46% to 89% of the variance of

functional tests used in that study (6-m walking speed, chair-stand time, and stair-climb time) as predicted by v_{opt}. The relationship of velocity and everyday functioning was also observed by other authors, for example, in women with chronic osteoarthritis (Kostka et al., 2014) and in the elderly (Mayson, Kiely, LaRose, & Bean, 2008; Sayers, Guralnik, Thombs, & Fielding, 2005). Bohannon (Bohannon, 1992) analyzed maximal (not optimal) velocity in post stroke patients and found a relationship between maximal velocity and gait function.

4.3 | Muscle power and functional performance

Other reports refer to the relationship between muscle power (measured with a different technique) and functional efficiency in stroke patients, particularly in regard to walking performance (Bohannon, 1992; Dawes et al., 2005; Saunders et al., 2008). In the study by Saunders et al (Saunders et al., 2008), lower limb extensor power in ambulatory people after stroke was a significant predictor of performance in functional tests. Participants with power lower than 1 W/kg were unable to get up from a chair without using their arms. Bohannon (Bohannon, 1992) reported a relationship between power of both paretic and nonparetic limbs with comfortable and maximum gait speed. Dawes et al. (2005) have shown that leg extensor power is related to walking performance after stroke (walking velocity, cadence, stance and swing time). In our study, P_{max}/kg also significantly affected the results of all functional measurements. This relationship was clear, both for TUG, where P_{max}/kg may directly influence an ability to perform activities like getting up from a chair and walking speed, but also in measurements that more generally evaluate functional performance, like IB and RMA.

4.4 | Age versus muscle function and functional performance

In multivariate analysis of post stroke patients, as opposed to healthy controls, TUG was even better predicted by P_{max}/kg or v_{opt} than by

the age. Similarly, both for BI and RMA, age did not determine the variability of stroke patients' results. Interestingly, as opposed to results from our control group and other studies concerning elderly people, we obtained no relationship between either P_{max} or υ_{opt} and the age in stoke survivors. Therefore, the influence of the stroke, or rather the accumulation of deficits related to the stroke, has more harmful consequences for muscle performance than aging per se (Sions, Tyrell, Knarr, Jancosko, & Binder-Macleod, 2012). In relatively healthy populations, gradual loss of muscle power and contraction velocity with age has been reported. Bonnefoy et al. (1998) indicated a 4.3% decline in υ_{opt} for every decade. This drop was already visible in people in their thirties and continued systematically until people reached their eighties (Kostka, 2005). The decrease in muscle power in the general population starts at about forty years of age and is more than 10% per decade (Kostka, 2005).

4.5 | Practical applications

Many important independent functioning activities of daily living (rising from a sitting position, regaining balance after stumbling, walking, climbing and descending stairs, etc.) require the capacity to perform short, relatively intensive actions that demand the generation of appropriate muscle power. This has also been confirmed in the present study. The respondents who obtained worse P_{max} and υ_{opt} results were characterized by weaker results in functional tests.

Because of these consequences of aging for muscle power and, hence, for many ADLs, it is recommended to pay attention to muscle power in older population by utilizing resistance exercise training and by incorporating higher-velocity training protocols (Chodzko-Zajko et al., 2009). Due to the clear relationship between P_{max} and υ_{opt} in regard to functional performance of patients after a stroke, rehabilitation programs should include protocols that increase the power and velocity in this group of patients, also in the presence of concomitant diseases such as diabetes (Gray, Ivanova, & Garland, 2012; Orr, Tsang, Lam, Comino, & Singh, 2006). Such training seems to be safe and gives significant improvement in muscle power accompanied with functional gains (Hunnicutt et al., 2016; Morgan, Embry, Perry, Holthaus, & Gregory, 2015; Vinstrup, Calatayud, Jakobsen, Sundstrup, & Andersen, 2016). Because power is a product of force and velocity, various types of strength training (including high-intensity training) can have a positive effect on muscle power and functional efficiency (Andersen et al., 2011; Vinstrup, Calatayud, Jakobsen, Sundstrup, Jay et al., 2016).

4.6 | Study limitations

The method of measuring muscle function used in our study does not give the opportunity to evaluate the power separately for each leg. However, the advantage of such a measurement is the ability to show cooperation between the limbs, as it is the case during basic everyday activities (e.g., walking or climbing stairs).

The limits of the study are that the results come from a monocentric study and some selection bias cannot also be excluded.

5 | CONCLUSIONS

Muscle power and muscle contraction velocity in patients who have had a stroke within three months are reduced markedly. These factors significantly affect functional performance. Muscle power and optimal shortening velocity are more important determinants of functional status than age in these stroke survivors. That is why rehabilitation programs for patients after stroke should include training that improves muscle power and incorporates higher-velocity protocols.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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REFERENCES

Andersen, L. L., Zeeman, P., Jørgensen, J. R., Bech-Pedersen, D. T., Sørensen, J., Kjær, M., & Andersen, J. L. (2011). Effects of intensive physical rehabilitation on neuromuscular adaptations in adults with poststroke hemiparesis. *Journal of Strength and Conditioning Research*, *25*(10), 2808–2817. https://doi.org/10.1519/JSC.0b013e31822a62ef

Bean, J. F., Leveille, S. G., Kiely, D. K., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2003). A comparison of leg power and leg strength within the InCHIANTI study: Which influences mobility more? *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *58*, 728–733. https://doi.org/10.1093/gerona/58.8.M728

Bohannon, R. W. (1992). Knee extension power, velocity and torque: Relative deficits and relation to walking performance in stroke patients. *Clinical Rehabilitation*, *6*(2), 125–131. https://doi.org/10.1177/026921559200600206

Bohannon, R. W. (2007). Muscle strength and muscle training after stroke. *Journal of Rehabilitation Medicine*, *39*(1), 14–20. https://doi.org/10.2340/16501977-0018

Bonnefoy, M., Kostka, T., Arsac, L. M., Berthouze, S. E., & Lacour, J. R. (1998). Peak anaerobic power in elderly men. *European Journal of Applied Physiology*, *77*, 182–188. https://doi.org/10.1007/s004210050318

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). College of Sports Medicine position stand. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, *41*(7), 1510–1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c

Clémençon, M., Hautier, C. A., Rahmani, A., Cornu, C., & Bonnefoy, M. (2008). Potential role of optimal velocity as a qualitative factor of physical functional performance in women aged 72 to 96 years. *Archives of Physical Medicine and Rehabilitation*, *89*(8), 1594–1599. https://doi.org/10.1016/j.apmr.2007.11.061

Collen, F. M., Wade, D. T., & Bradshaw, C. M. (1990). Mobility after stroke: Reliability of measures of impairment and disability. *International Disability Studies*, *12*(1), 6–9. https://doi.org/10.3109/03790799009166594

Collin, C., Wade, D. T., Davies, S., & Horne, V. (1988). The Barthel ADL Index: A reliability study. *International Disability Studies*, *10*(2), 61–63. https://doi.org/10.3109/09638288809164103

Cramer, S. C. (2008). Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. *Annals of Neurology*, *63*(3), 272–287. https://doi.org/10.1002/ana.21393

Dawes, H., Smith, C., Collett, J., Wade, D., Howells, K., Ramsbottom, R., … Sackley, C. (2005). A pilot study to investigate explosive leg extensor power and walking performance after stroke. *Journal of Sports Science & Medicine*, *4*(4), 556–562.

Flansbjer, U. B., Holmbäck, A. M., Downham, D., Patten, C., & Lexell, J. (2005). Reliability of gait performance tests in men and women with hemiparesis after stroke. *Journal of Rehabilitation Medicine*, *37*(2), 75–82. https://doi.org/10.1080/16501970410017215

Gerrits, K. H., Beltman, M. J., Koppe, P. A., Konijnenbelt, H., Elich, P. D., de Haan, A., & Janssen, T. W. (2009). Isometric muscle function of knee extensors and the relation with functional performance in patients with stroke. *Archives of Physical Medicine and Rehabilitation*, *90*(3), 480–487. https://doi.org/10.1016/j.apmr.2008.09.562

Gray, V. L., Ivanova, T. D., & Garland, S. J. (2012). Effects of fast functional exercise on muscle activity after stroke. *Neurorehabilitation and Neural Repair*, *26*(8), 968–975. https://doi.org/10.1177/1545968312437944

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New England Journal of Medicine*, *332*(9), 556–561.

Hunnicutt, J. L., Aaron, S. E., Embry, A. E., Cence, B., Morgan, P., Bowden, M. G., & Gregory, C. M. (2016). The effects of POWER training in young and older adults after stroke. *Stroke Research and Treatment*, *2016*, 1–5. https://doi.org/10.1155/2016/7316250

Hunnicutt, J. L., & Gregory, C. M. (2017). Skeletal muscle changes following stroke: A systematic review and comparison to healthy individuals. *Topics in Stroke Rehabilitation*, *24*(6), 463–471. https://doi.org/10.1080/10749357.2017.1292720

Jørgensen, L., & Jacobsen, B. K. (2001). Changes in muscle mass, fat mass, and bone mineral content in the legs after stroke: A 1 year prospective study. *Bone*, *28*(6), 655–659. https://doi.org/10.1016/S8756-3282(01)00434-3

Kostka, J. S., Czernicki, J. W., & Kostka, T. J. (2014). Association of muscle strength, power, and optimal shortening velocity with functional abilities of women with chronic osteoarthritis participating in a multimodal exercise program. *Journal of Aging and Physical Activity*, *22*(4), 564–570. https://doi.org/10.1123/JAPA.2012-0125

Kostka, J., Czernicki, J., Pruszyńska, M., & Miller, E. (2017). Strength of knee flexors of the paretic limb as an important determinant of functional status in post-stroke rehabilitation. *Neurologial Neurochirurgia Polska*, *51*(3), 227–233. https://doi.org/10.1016/j.pjnns.2017.03.004

Kostka, J., Fajkowska, A., & Miller, E. (2017). The impact of stroke on the power and shortening velocity of the muscles - preliminary study. *Fizjoterapia Polska*, *17*(2), 16–22.

Kostka, T. (2005). Quadriceps maximal power and optimal shortening velocity in 335 men aged 23–88 years. *European Journal of Applied Physiology*, *95*(2–3), 140–145.

Lee, C. D., Folsom, A. R., & Blair, S. N. (2003). Physical activity and stroke risk: A meta-analysis. *Stroke*, *34*(10), 2475–2481. https://doi.org/10.1161/01.STR.0000091843.02517.9D

Lincoln, N., & Leadbitter, D. (1979). Assessment of motor function in stroke patients. *Physiotherapy*, *65*(2), 48–51.

Mayson, D. J., Kiely, D. K., LaRose, S. I., & Bean, J. F. (2008). Leg strength or velocity of movement: Which is more influential on the balance of mobility limited elders? *American Journal of Physical Medicine & Rehabilitation*, *87*(12), 969–976. https://doi.org/10.1097/phm.0b013e31818dfee5

Morgan, P., Embry, A., Perry, L., Holthaus, K., & Gregory, C. M. (2015). Feasibility of lower-limb muscle power training to enhance locomotor function poststroke. *Journal of Rehabilitation Research and Development*, *52*(1), 77–84. https://doi.org/10.1682/JRRD.2014.04.0109

Orr, R., Tsang, T., Lam, P., Comino, E., & Singh, M. F. (2006). Mobility impairment in type 2 diabetes: Association with muscle power and effect of Tai Chi intervention. *Diabetes Care*, *29*(9), 2120–2122. https://doi.org/10.2337/dc06-1130

Podsiadlo, D., & Richardson, S. (1991). The timed "up & go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, *39*, 142–148.

Prado-Medeiros, C. L., Silva, M. P., Lessi, G. C., Alves, M. Z., Tannus, A., Lindquist, A. R., & Salvini, T. F. (2012). Muscle atrophy and functional deficits of knee extensors and flexors in people with chronic stroke. *Physical Therapy*, *92*(3), 429–439. https://doi.org/10.2522/ptj.20090127

Rantanen, T., Era, P., & Heikkinen, E. (1997). Physical activity and the changes in maximal isometric strength in men and women from the age of 75 to 80 years. *Journal of the American Geriatrics Society*, *45*(12), 1439–1445. https://doi.org/10.1111/j.1532-5415.1997.tb03193.x

Saunders, D. H., Greig, C. A., Young, A., & Mead, G. E. (2008). Association of activity limitations and lower-limb explosive extensor power in ambulatory people with stroke. *Archives of Physical Medicine and Rehabilitation*, *89*(4), 677–683. https://doi.org/10.1016/j.apmr.2007.09.034

Sayers, S. P., Guralnik, J. M., Thombs, L. A., & Fielding, R. A. (2005). Effect of leg muscle contraction velocity on functional performance in older men and women. *Journal of the American Geriatrics Society*, *53*, 467–471. https://doi.org/10.1111/j.1532-5415.2005.53166.x

Sions, J. M., Tyrell, C. M., Knarr, B. A., Jancosko, A., & Binder-Macleod, S. A. (2012). Age- and stroke-related skeletal muscle changes: A review for the geriatric clinician. *Journal of Geriatric Physical Therapy*, *35*(3), 155–161. https://doi.org/10.1519/JPT.0b013e318236db92

Stavric, V. A., & McNair, P. J. (2012). Optimizing muscle power after stroke: A cross-sectional study. *Journal of Neuroengineering and Rehabilitation*, *27*(9), 67.

Vinstrup, J., Calatayud, J., Jakobsen, M. D., Sundstrup, E., & Andersen, L. L. (2016). Focusing on Increasing Velocity during Heavy Resistance Knee Flexion Exercise Boosts Hamstring Muscle Activity in Chronic Stroke Patients. *Neurology Research International*, *2016*, 6523724. https://doi.org/10.1155/2016/6523724

Vinstrup, J., Calatayud, J., Jakobsen, M. D., Sundstrup, E., Jay, K., Brandt, M., … Andersen, L. L. (2016). Electromyographic comparison of elastic resistance and machine exercises for high-intensity strength training in patients with chronic stroke. *Archives of Physical Medicine and Rehabilitation*, *97*(3), 429–436. https://doi.org/10.1016/j.apmr.2015.10.099

Wu, D., Wang, L., Teng, W., Huang, K., & Shang, X. (2015). Correlation of post-stroke fatigue with glucose, homocysteine and functional disability. *Acta Neurologica Scandinavica*, *131*(6), 400–404. https://doi.org/10.1111/ane.12300