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Strength of knee flexors of the paretic limb as an important determinant of functional status in post-stroke rehabilitation

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ABSTRACT

Objective: The purpose of the study was to assess the effectiveness of the multi-modal exercise program (MMEP) in patients after stroke, and to identify muscles that are the best predictors of functional performance and changes in functional status in a 3-week rehabilitation program.
Methods: Thirty-one post-stroke patients (60.6 ± 12.7 years) participating in a 3-week MMEP took part in the study. Measurements of extensor and flexor strength of the knee (F_{ext}, F_{flex}) were done. Functional performance was measured using Timed Up & Go test (TUG), 6-Minute Walk Test (6-MWT) and Tinetti Test.
Results: The rehabilitation program improved all the results of functional tests, as well as the values of strength in the patients. Both baseline and post-rehabilitation functional status was associated with knee flexor and extensor muscle strength of paretic but not of non-paretic limbs. At baseline examination muscle strength difference between both F_{flex} kg^{-1} and F_{ext} kg^{-1} had an influence on functional status. After rehabilitation the effect of muscle strength difference on functional status was not evident for F_{ext} kg^{-1} and, interestingly, even more prominent for F_{flex} kg^{-1}.
Conclusions: MMEP can effectively increase muscle strength and functional capacity in post-stroke patients. Knee flexor muscle strength of the paretic limb and the knee flexor difference between the limbs is the best predictor of functional performance in stroke survivors.

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1. Introduction

Stroke is associated with a number of motor and neuropsychological consequences resulting in a deterioration of functional status and a reduction in the activities of daily living [1,2]. These changes can not only affect muscle weakness, balance and gait, but also result in cognition and mood impairment [1,3].

The muscles of the lower limbs play a key role in maintaining walking ability, keeping balance and rising form the bed or toilet, and as a consequence, in preserving independence in daily life [4]. Most significantly, they are required for an efficient gait, and muscle weakness may be a more important factor limiting gait efficiency (especially gait speed) than spasticity [5,6]. Following a stroke, changes in gait patterns related to asymmetry in step length and time loading, as well as the prolongation of the double support phase, result in lower gait speed and decreased walking endurance [3,7,8]. Several studies have reported correlations between the strength of different muscle groups and such aspects of functional capacity as gait endurance, gait speed or balance in stroke survivors [3,9,10]. Most relevant studies have revealed an association between weakness of the paretic side with functional efficiency [11]. Several authors have observed reductions of muscle strength, not only in the paretic but also the non-paretic side, in comparison to an able-bodied group [2,12,13].

While many training programs have been found to be effective in post-stroke rehabilitation, the precise role of different groups of muscles from the paretic and non-paretic side is still being discussed. As strokes are known to result in a range of impairments, including muscle weakness, reduced endurance, decreased balance, coordination disorders or spasticity, any intended rehabilitation program should aim to influence the underlying impairments, hence the creation of the multi-modal exercise program (MMEP).

Many studies have assessed the effects of different kinds of training on muscle strength or function [14–16], but relatively few assessed prospectively physical functioning in relation to lower limb muscle strength in post-stroke patients [17,18]. Therefore, the purpose of the study was to assess the effectiveness of the multi modal exercise program (MMEP) in patients after stroke and to identify the muscle groups (knee extensors and flexors in both paretic and non-paretic leg) that are the best predictors of functional performance and changes in functional status in a 3-week rehabilitation program. We hypothesized that in this group of patients, the strength of the knee flexor muscles may be more important than that of the extensors, especially on the paretic side.

2. Methods

2.1. Subjects

The study was performed with patients admitted to the Department of Rehabilitation for the purpose of functional rehabilitation more than one month following a stroke. For safety reasons, patients referred to the rehabilitation unit with diagnosis of myocardial infarction or orthopedic surgery established within the previous three months were not included in the study. Furthermore, patients with cardiac contraindications for exercise tests or who lacked the ability to perform tests due to motor system dysfunctions, such as pain, limited range of motion or a spasticity score >2 on a modified Ashworth scale, were excluded from the study. The inclusion criteria comprised the presence of hemiparesis after stroke, the ability to understand and execute commands, and the ability to perform the exercise tests and give written consent to participate in the study. Of the 392 patients hospitalized during a one-year period in the rehabilitation ward, 19 women and 14 men met the inclusion criteria. As two subjects refused to participate further in all the tests, 31 patients aged 27–87 years (60.6 ± 12.7 years) ultimately participated in the study. Baseline characteristics of the study group is shown in Table 1.

Table 1 – Baseline participants' characteristics.

Variable	Mean ± SD	Median (25–75%)
Age (years)	60.7 ± 12.7	59.0 (52.0–72.0)
Sex (male/female)	14/17	
Education (years)	12.8 ± 3.9	12 (10–17)
Number of chronic conditions (including stroke)	3.9 ± 1.9	4 (2–5)
Number of medications	7.5 ± 2.4	7.5 (6–9)
Paretic side (right/left)	11/20	
Type of stroke (ischemic/ hemorrhagic)	29/2	
Time after stroke (months)	26.7 ± 38.2	16 (2–30)
Body mass (kg)	75.3 ± 15.1	79 (63–84)
Height (m)	1.66 ± 0.09	1.66 (1.58–1.74)
BMI	27.3 ± 4.6	27.3 (24.4–30.19)
Activities of daily living (ADL; 0–6)	5.32 ± 0.63	5.5 (5–6)

Eleven persons had only undergone primary education, another 11 had left school after completing their secondary education and nine participants had graduated from university. All the patients were diagnosed with stroke, ten with osteoarthritis, nine with coronary heart disease, five with heart failure, two with osteoporosis, one with chronic pulmonary disease, nine with gastrointestinal disease, two with myocardial infarction and two with cancer. Twenty-five subjects were treated for hypertension, 16 for hypercholesterolemia and 10 for diabetes. The average number of medications taken was 7.47 ± 2.40 per day and the pharmacological treatment was maintained during the whole rehabilitation period. The study was approved by the Bioethics Committee.

2.2. Protocol

All the patients underwent physical examination prior to the study. During the interview, information on socio-economic status, smoking, current and previous illnesses and current medication was obtained. The body mass index (BMI, kg m^{-2}) was also calculated. In all 31 patients, two sets of examinations were performed: the first on the first day, and the second three weeks later, on the final day of hospitalization.

All patients participated in a three-week multi-modal exercise rehabilitation program. Physical exercise, divided equally between resistance, endurance and balance training, was applied at least one hour a day. Resistance training of low to moderate intensity consisted of elements of functional tasks such as loading the limbs via different tasks, sit-to-stand from a chair, climbing stairs, and raising and lowering the heels in a standing position. In addition, passive and active movements were performed with the physical therapist, and movements with resistance were applied by the physical therapist. Endurance training included aerobic (bicycle, treadmill) exercises and gait training. Aerobic exercise intensity was set to be low to moderate, with a rating of perceived exertion between 10 and 13 on the 6- to 20-point Borg scale [19]. These exercises were complemented by balance training, transfer training and stretching exercises. The lifestyle education of the patient was also taken into account. Patients received no other rehabilitation treatment. Exercise and other treatments were carried out for six days each week, from Monday to Saturday.

2.3. *Strength of knee extensors and flexors*

Measurements of extensor (F_{ext}) and flexor (F_{flex}) strength of the knee were done in an armchair UPR-02 A/S with Moment II software (Accuro-Sumer, Warsaw, Poland). The study was performed in a seated position with stabilization of the distal part of the thigh and torso at the level of the upper iliac spine. The test for the knee extensor muscles was performed at an angle of 75° flexion of the knee joint and at an angle of 30° flexion for the knee flexor muscles. At a given signal, the patient pressed the lever for 10 s (isometric tension) in the direction of extension (for F_{ext}) or in the direction of flexion (for F_{flex}). The non-paretic limb was tested first, followed by the paretic limb. Each patient was allowed two trials for each leg, with the highest recorded values being used for the analysis. To better illustrate the ability to move body weight, the results of the strength test are demonstrated per kilograms of body mass (Nm kg^{-1}). The difference between paretic and non-paretic limb was calculated.

2.4. *Functional performance*

Functional performance was measured using three tests and scales: Timed Up & Go test (TUG) [20], 6-Minute Walk Test (6-MWT) [21] and Tinetti Test [22]. The Timed Up & Go test assesses the basic functions of daily life in the following sequence: standing up from a standard height chair and walking for a short distance (3 m), returning and sitting back down as quickly as possible. The time to perform these tasks was measured on a stopwatch to the nearest 0.1 s. The patients were allowed to use their own walking aids (e.g. stick, crutch or walker). Each patient performed the test twice, with the better result being used for the analysis.

The 6-MWT measures the distance covered by the patient during a 6-minute walk along the hospital corridor and back again. The subjects could perform the task at their desired speed and could use their own walking aids. This test was designed to evaluate the cardiorespiratory capacity of patients with cardiac and respiratory disease, but can also be used to assess the functional walking ability of stroke patients [6].

The Tinetti balance and gait evaluation combines an assessment of balance with gait, with a maximum total score of 28 points: 16 points for the balance component and 12 for gait. In general, patients who score in the range of 19–24 have an increased risk of falls while patients who score below 19 are classified into a high fall risk group.

2.5. *Statistical analysis*

The results were verified for normality of distribution and equality of variances. The paired Student's t-test and sign test were used to assess the impact of rehabilitation on dependent variables. To assess the correlation between variables, Pearson's and Spearman correlation coefficients were calculated. Multiple linear regression (with forward stepwise technique) was used with all independent variables with $p < 0.05$ in bivariate analysis to select variables that independently predict results in functional tests. For numeric variables, the results are presented as mean (±SD). The limit of statistical significance was set at $p < 0.05$ for all the analyses.

3. Results

The baseline characteristics and influence of rehabilitation on the examined variables is shown in Table 2. At baseline, the

Table 2 – Influence of a 3-week rehabilitation program on anthropometric data, functional capacities, strength (Nm kg^{-1}) and strength differences between limbs in patients after stroke.

	Before rehabilitation	After rehabilitation	% change	Significance
Body mass (kg)	75.31 ± 15.10	74.40 ± 14.18	−1.21	$p < 0.01$
BMI (kg·m^{-2})	27.31 ± 4.57	27.01 ± 4.30	−1.1	$p < 0.01$
TUG test (s)	15.09 ± 8.60	12.53 ± 6.98	−16.97	$p < 0.001$
Tinetti test (points)	20.45 ± 5.92	22.0 ± 5.53	7.58	$p < 0.001$
6-MWT (m)	269.26 ± 130.5	305.66 ± 134.04	13.52	$p < 0.001$
F_{ext} non paretic limb	1.08 ± 0.54	1.22 ± 0.63	12.96	$p < 0.01$
F_{ext} paretic limb	0.73 ± 0.52	0.90 ± 0.60	23.29	$p < 0.001$
F_{flex} non paretic limb	0.63 ± 0.36	0.72 ± 0.36	14.29	$p < 0.05$
F_{flex} paretic limb	0.38 ± 0.32	0.50 ± 0.37	31.58	$p < 0.001$
Difference for F_{ext}	0.35 ± 0.25	0.32 ± 0.22	−8.58	NS
Difference for F_{flex}	0.24 ± 0.25	0.22 ± 0.27	−8.33	NS

NS, not significant; BMI, body mass index; TUG, Timed Up & Go test; 6-MWT, 6-Minute Walking test.
F_{ext}, knee extensor strength; F_{flex}, knee flexor strength; TUG test: higher score - worse functional performance. Tinetti test and 6-MWT: higher score - better functional performance.

respective strengths of the knee extensors and flexors of the affected side were 32.4% and 39.7% weaker than those of the non-affected side. Decreases in body mass and BMI were found during rehabilitation. The rehabilitation program improved all the results of the functional tests, as well as the strength values. The changes observed in strength differences between the limbs following rehabilitation were not statistically significant for both extensors and flexors of the knee muscles.

The baseline relationship between the functional test results and muscle strength and strength differences between the limbs are shown in Table 3. Similarly, correlations between functional status variables and muscle strength and strength differences between the limbs after rehabilitation are presented in Table 4. As can be seen from the two tables, both baseline and post-rehabilitation functional status were related to the F_{flex} and F_{ext} of the paretic but not the non-paretic limbs, with the exception of the relationship between the Tinetti Test and F_{ext} after rehabilitation. At the baseline, the difference in muscle strength between both F_{flex} and F_{ext} had an influence on functional status. After rehabilitation, the influence of muscle strength difference on functional status was not evident for F_{ext} but it was more prominent for F_{flex}.

Multiple linear regression analysis.

At baseline (before rehabilitation), TUG was negatively predicted by F_{flex} of the paretic limb and favorably by the difference in F_{flex}:

TUG = 16.0–11.81 × F_{flex} paretic limb + 14.64 × F_{flex} difference (adjusted R^2 = 42.04, SEE = 6.55)

Tinetti test was favorably predicted by F_{flex} of the paretic limb and negatively by the difference of F_{flex}:

Tinetti = 19.65 + 7.40 F_{flex} paretic limb − 8.23 F_{flex} difference (adjusted R^2 = 29.75, SEE = 4.96)

6MWT was favorably predicted by F_{ext} of the paretic limb and negatively by the difference of F_{flex}:

6-MWT = 259.54 + 112.78 F_{ext} paretic limb − 295.06 F_{flex} difference (adjusted R^2 = 46.48, SEE = 95.47)

After rehabilitation, TUG was negatively predicted by F_{ext} of the paretic limb and favorably by the difference of F_{flex}:

TUG = 12.48 − 3.71 F_{ext} paretic limb + 15.46 F_{flex} difference (adjusted R^2 = 44.28, SEE = 5.21)

The only predictor of Tinetti test was the difference of F_{flex}:

Tinetti = 24.72–12.42 F_{flex} difference (adjusted R^2 = 33.74, SEE = 4.50)

6-MWT was favorably predicted by F_{ext} of the paretic limb and negatively by the difference of F_{flex}:

6MWT = 302.89 + 70.37 F_{ext} paretic limb − 276.38 F_{flex} difference (adjusted R^2 = 38.81, SEE = 104.85)

Correlations between relative (%) changes (Δ) in functional status and changes in muscle strength and the strength difference between limbs during the three-week rehabilitation program are shown in Table 5.

Improvements in both F_{ext} and F_{flex} of the paretic limb after the three-week MMEP were transferred to the improvement in functional abilities in every applied test. Also, the improvement of the F_{ext} of the non-paretic limb was correlated with improvements in the TUG and Tinetti tests. No correlations were observed between changes in the strength difference

Table 3 – Baseline correlations between functional status variables and muscle strength and strength differences between limbs.

	F_{ext} non paretic limb	F_{ext} paretic limb	F_{flex} non paretic limb	F_{flex} paretic limb	Difference for F_{ext}	Difference for F_{flex}
TUG test (s)	NS	$r = -0.41^{*}$	NS	$r = -0.54^{**}$	$r = 0.37^{*}$	$r = 0.53^{**}$
Tinetti test (points)	NS	$r = 0.40^{*}$	NS	$r = 0.48^{**}$	$r = -0.42^{*}$	$r = -0.44^{*}$
6-MWT (m)	NS	$r = 0.43^{*}$	NS	$r = 0.54^{**}$	$r = -0.46^{**}$	$r = -0.55^{**}$

NS, not significant.

F_{ext}, knee extensor strength; F_{flex}, knee flexor strength; BMI, body mass index; TUG, Timed Up & Go test; 6-MWT, 6-Minute Walking test. TUG test: higher score - worse functional performance. Tinetti test and 6-MWT: higher score - better functional performance.

* $p < 0.05$.

** $p < 0.01$.

Table 4 – Correlations between functional status variables and muscle strength and strength differences between limbs after rehabilitation.

	F_{ext} non paretic limb	F_{ext} paretic limb	F_{flex} non paretic limb	F_{flex} paretic limb	Difference for F_{ext}	Difference for F_{flex}
TUG test (s)	NS	$r = -0.36^{*}$	NS	$r = -0.51^{**}$	NS	$r = 0.61^{***}$
Tinetti test (points)	NS	NS	NS	$r = 0.41^{*}$	NS	$r = -0.60^{***}$
6-MWT (m)	NS	$r = 0.36^{*}$	NS	$r = 0.47^{**}$	NS	$r = -0.57^{***}$

NS, not significant.

F_{ext}, knee extensor strength; F_{flex}, knee flexor strength; TUG, Timed Up & Go test; 6-MWT, 6-Minute Walking test. TUG test, higher score - worse functional performance. Tinetti test and 6-MWT, higher score - better functional performance.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

Table 5 – Correlations between relative (%) changes (Δ) in functional status and changes in muscle strength and strength difference between limbs with a 3-week rehabilitation program.

Quantitative variable	ΔTUG test (s)	ΔTinetti test (points)	Δ6-MWT (m)
ΔF_{ext} non paretic limb	$r = -0.48^{**}$	$r = 0.36^{*}$	NS
ΔF_{ext} paretic limb	$r = -0.72^{***}$	$r = 0.77^{***}$	$r = 0.77^{***}$
ΔF_{flex} non paretic limb	NS	NS	NS
ΔF_{flex} paretic limb	$r = -0.47^{**}$	$r = 0.53^{**}$	$r = 0.68^{***}$
Δ difference for F_{ext}	NS	NS	NS
Δ difference for F_{flex}	NS	NS	NS

NS, not significant.

F_{ext}, knee extensor strength; F_{flex}, knee flexor strength; TUG, Timed Up & Go test; 6-MWT, 6-Minute Walking test. TUG test: higher score - worse functional performance. Tinetti test and 6-MWT: higher score - better functional performance.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

between limbs (both F_{ext} and F_{flex}) and changes in functional status during rehabilitation.

4. Discussion

Despite the fact that MMEP is widely used in clinical practice in patients after stroke, most studies focussing on the effects of training tend to deal with selected elements, e.g. resistance training [14,18,23], endurance training [24], gait training [25] or functional training [17].

The present study shows that MMEP can effectively increase muscle strength and functional capacity in post-stroke patients, but does not have any clear influence on the reduction of the differences for both extensors and flexors of the knee muscles between the two limbs. The muscle strength of the knee flexor of the paretic limb, and more importantly the difference in knee flexor strength between the limbs, are the best predictors of functional performance before and after a three-week rehabilitation program.

Deficits in muscle strength have been reported in both the paretic and non-paretic sides in post stroke survivors [2,12,13]. Despite this, our findings indicate no significant relationship between the strength of the non-paretic limb and the results of functional tests, neither at baseline nor after the rehabilitation program. This observation is consistent with some previous studies [3,11]. Flansbjer et al. [11] found that while the muscular strength of the paretic knee extensors and flexors to be correlated with all functional tests (gait speed, stair climbing, 6MWT), the same was not the case for the non-paretic side. Similar results were found by Nasciutti-Prudente et al. [3], with paretic knee flexor torque being the best predictor of gait speed, responsible for 61% of the variance. The muscles of the non-paretic side and knee extensors of paretic side had no influence on gait speed. Kim and Eng [26] report a significant relationship between functional performance (gait speed and stair climbing) and the strength of the knee flexors, but not with the knee extensors, of both the paretic and non-paretic sides. They suggest that non-paretic limb function should not be neglected during the therapy, because the correlations of strength and function observed for the non-paretic limb were as high as those for the paretic limb [26].

Our findings highlight the importance of the knee flexor muscle group in maintaining the functional capacity of patients following a stroke. Weakness of the paretic knee flexors was found to be a more limiting factor than weakness of any other muscle group of the lower limbs. This may be the key factor influencing functional performance following a stroke. The knee flexors play an important role in gait with their concentric work functionally shortening the transferred limb during the swing phase [3]. Knee dysfunction is associated with reduced flexion during the swing phase, which is a fundamental component of impaired advancement of the paretic limb [27]. Flexors also function to prevent knee hyperextension. In the initial contact of the stance phase they eccentrically control knee flexion, and may cause *genu recurvatum* when weakened [28]. Additionally, the strength of the knee flexors in post-stroke patients may be hampered by spasticity of the antagonistic rectus femoris [29]. Elimination of this blockage by botulinum toxin injection in the rectus femoris can change knee flexion during the swing phase, resulting in functional improvements and decreased energy cost associated with walking in post-stroke patients [29,30].

Despite the fact that the greatest relative enhancement associated with the three-week training period was found for F_{flex} of the paretic side (31.6%), this was still the most important factor that limited functional performance in our post-stroke patients. The influence of training on the paretic side may have been too little to improve physical functioning. Following MMEP, a greater difference was observed between knee flexor strength (paretic F_{flex} = 69.4% of non-paretic F_{flex}) than extensor strength (paretic F_{ext} = 73.8% of non-paretic F_{ext}). Also, the multiple linear regression analysis indicated that functional performance was mainly predicted by the difference between F_{flex} values, both before and after rehabilitation. Hence, knee flexor strength on the paretic side and the difference between F_{flex} may be one of the most limiting factors in the effectiveness of post-stroke rehabilitation.

Our study confirms the effectiveness of a three-week period of MMEP. The variety of tasks incorporated in MMEP stimulate muscle strength, endurance, balance and coordination which result in demonstrated improvements in speed, endurance and quality of gait. Some studies with resistance training report improvements in muscle strength, but not always in functional status. Weiss et al. [31] found a 12-week period of high intensity strength training (hip flexion, abduction, extension; knee extension and leg press in sitting position), taking place twice a week, to be associated with improvement in strength in all trained muscle groups on both the paretic and non-paretic sides in subjects who had suffered a stroke at least one year previously. However, despite these increases in overall muscle strength, gains in functional performance were observed only for repeated chair stand time and stair climb time, with gait velocity and leg stance time remaining unchanged. With a similar training schedule, Ouellette et al. [23] obtained improvements in muscle strength and self-reported lower extremity function, as well as reduced disability in a group of stroke patients, but changes in functional results (6-MWT, stair climb time, chair rise time, gait velocity) were similar to those of the control group.

Muscle strength is only one of the elements necessary for smooth functioning. In post-stroke patients, task-oriented strength training may bring better functional effects. Elements of this kind of training were used also in our program. One study with task-oriented strength training demonstrated that the achieved strength gain was associated with gains in functional status [17], with changes in the strength of the paretic limbs (most of all F_{ext}) being connected with improvements in functional tests. The strongest relationship with functional improvement was observed with the increase of F_{ext} of the paretic side, and the greatest strength gains in this muscle group may result in the greatest functional gains [17]. Similarly, ΔF_{ext} of the paretic side was found to have a strong influence on the results of the present study. This may be due to the fact that many of the proposed functional exercises, both in task-oriented strength training and in MMEP, such as sit-to-stand from a chair, climbing stairs and step-up onto blocks, significantly engage the knee extensor muscles.

An important finding of our study was that the improvements in muscle strength observed after the three-week MMEP were transferred to improvements in functional abilities in every test applied. These relationships mainly concerned the muscle strength (F_{ext} and F_{flex}) of the paretic limb, but lesser gains were also observed in the F_{ext} of the non-paretic side. Nevertheless, correlations between relative changes in functional status and changes in muscle strength were greatest for the F_{ext} of the paretic limb, which may be due to the fact that absolute changes in F_{ext} of the paretic limbs were greater than those observed for F_{flex}. No correlations were observed between changes in the difference of muscle strength between the paretic and non-paretic sides and changes in functional status influenced by training. These differences did not change after rehabilitation ($p > 0.05$): they were probably too small to have an impact on functional status.

The limitation of this study is its relatively small number of participants, but despite this small sample size, significant improvements in functional status could be observed. Another limitation was the lack of any control group based on subjects who did not exercise or took part in a different exercise program. Unfortunately, it would be difficult to include such a control group because MMEP is used as standard therapy in our ward for patients after stroke.

5. Conclusions

The difference between the strength of the knee flexors appears to be the most important measure limiting functional status after rehabilitation. In future studies, and in the preparation of rehabilitation programs for post-stroke patients, a higher priority should be given to the action of the knee flexor muscles and reducing the difference in strength between the paretic/non-paretic limbs.

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Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; Uniform Requirements for manuscripts submitted to Biomedical journals.

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