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Analysis of upper limb muscle strength in the early phase of brain stroke

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Purpose: The aim of this study was to determine the muscles with the lowest strength in non-affected (non-A) and affected upper limb (A), to assess differences between men and women and to correlate these values with age in patients after stroke. *Methods*: Sixty patients (40 male, 20 female), hospitalized in Neurorehabilitation Ward, 1–2 weeks after stroke, were included in the study. Their age ranged from 50 to 80 years with a mean (sd) of 65.5 (18.7) years. Muscle force values from upper limb muscles were measured using the MicroFet 2 hand-held dynamometer. The results are given in Newtons [N], mean values of muscular force, effect sizes and confidence intervals are displayed as Cohen's *d* and 95% CI were determined. Moreover, we made the coefficients correlation for differences in muscular force versus the Rivermead Motor Assessment (RMA) arm section. *Results*: Strength of (A) upper limb in comparison to (non-A) was 39% weaker. The severely affected muscle groups were the shoulder flexion 41% (women) versus 46% (men); elbow flexion 39% (women) versus 31% (men); wrist extension 36% (women) versus 42% (men). No significant correlations were found between muscle strength results and RMA or age. *Conclusions*: Muscle force of (A) upper limb after stroke demonstrates a 39% decrease. Men show more significant decrease than women (40% vs. 35%). Functional assessment in RMA values shows the better results in women (4.9 ± 4.1) than men (3.4 ± 3.2).

Key words: *muscle strength, upper limb, stroke, dynamometer*

1. Introduction

Muscle weakness, especially on the side contralateral to the brain lesion, is one of the most common symptoms of stroke [3], [11]. In hemiparetic stroke survivors, deficit of muscle strength is considered to be an important factor limiting functional performance [18], [21], [29], physical activity [1] and quality of life [15]. Some authors suggest that loss of strength is an even more significant contributor than spasticity [21], [29] and loss of dexterity [9] to physical disability after stroke. An evaluation of muscle strength may be a useful indicator of functional recovery after stroke and outcomes of stroke rehabilitation [16], [29]. Knowledge about muscle deficits and strength weakness patterns is also helpful in creating goals and rehabilitation programs.

Strength deficits in post-stroke survivors have been described by various investigators in relation to the ipsilateral limb [11], [18], [27], to the control group [11] or to the reference values [3], but the patterns of distribution of weakness between various muscle groups (e.g., flexors/extensors) and joints (proximal/distal) after stroke remain inconsistent, particularly with stereotyped approach (in upper limb, extensors and distal muscle are more weakened than flexors and proximal muscle). A pattern of weakness in the extensors (upper limbs) or flexors (lower limbs), is known as "pyramidal weakness" [14].

In upper extremities, absolute muscle strength is generally greater for proximal than for distal muscle groups both in healthy individuals [4] and poststroke survivors [3], [13], [27], but distribution for muscle strength between antagonistic muscle groups is different in various studies. For example, Dewald and Beer

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[13] reported that the absolute muscle strength of shoulder flexors in hemiparetic patients is greater than that of extensors, whereas other studies [4], [19] showed that elbow extensors in the healthy limb were a bit predominant.

Collected data show that muscle strength can be measured with a hand held dynamometer [27] or stationary equipment [12], [19]. The use of hand-held dynamometer has many advantages over static dynamometers, such as lower cost, ease of transport, the possibility of engaging a number of muscle groups as well as space saving. Good reliability and validity of this device was confirmed in several studies [24]–[26]. Therefore, this instrument can be regarded as a useful tool for muscle strength assessment in a clinical setting.

Objectives in this study were: first, to determine the weakest muscles of non-affected upper limb (non-A) and affected side (A); second, to find differences between man and woman; third, to correlate of these values with age and functional performance.

2. Materials and methods

Sixty patients (40 male, 20 female), hospitalized in Neurorehabilitation Ward, 1–2 weeks after stroke were included in the study. Their age ranged from 50 to 80 years with a mean (sd) of 65.5 (18.7) years. An assessment including sociodemographic data and health status was performed with each subject (Table 1). To evaluate functional performance Rivermead Motor Assessment (RMA) arm section was used. Muscle strength understood as maximum voluntary force that subject was able to exert on the dynamometer under specific testing conditions [6] for shoulder (flexion, abduction, extension, external and internal rotation), elbow (flexion and extension) and wrist (extension) were measured using a MicroFet 2 hand-held dynamometer (Hoggan Health Industries, UT, USA). Dynamometer was new and was calibrated according to the manufacturers manual. Proper positioning and stabilization was provided to avoid compensatory

Table 1. Characteristics of the study population

	Female	Male	Total
n	20 (33%)	40 (67%)	60 (100%)
Age (years)	69.9 ± 10.1	63.4 ± 9.1	65.6 ± 9.8
Right paresis (%)	7 (35%)	20 (50%)	27 (45%)
Leftparesis (%)	13 (65%)	20 (50%)	33 (55%)
Arterial hypertension (%)	16 (80%)	36 (90%)	52 (87%)
Diabetes (%)	4 (20%)	9 (22%)	13 (22%)

Table 2. Results of the manual evaluation of muscular force in non-paretic and paretic upper limb.
The results are given in Newtons [N] as the mean value ± its standard deviation

Movement	Female			Male			Total		
	Non-A	A	*p*	Non-A	A	*p*	Non-A	A	*p*
Shoulder flexion	90.0 ± 27.2	53.2 ± 23.9	$p < 0.001$	115.6 ± 48.0	61.9 ± 42.7	$p < 0.001$	107.1 ± 43.7	59.0 ± 37.5	$p <0.001$
Shoulder abduction	83.6 ± 26.7	56.1 ± 24.5	$p < 0.001$	108.6 ± 35.7	64.3 ± 39.8	$p < 0.001$	100.3 ± 34.9	61.6 ± 35.5	$p < 0.001$
Shoulder extension	102.7 ± 32.1	68.2 ± 20.9	$p < 0.001$	147.7 ± 43.6	87.3 ± 51.2	$p < 0.001$	132.7 ± 45.2	80.9 ± 44.2	$p < 0.001$
Shoulder rotation ext.	69.6 ± 25.3	44.0 ± 19.9	$p < 0.001$	101.2 ± 31.6	57.0 ± 35.0	$p < 0.001$	90.7 ± 33.0	52.7 ± 31.2	$p < 0.001$
Shoulder rotation int.	80.5 ± 27.6	54.9 ± 21.6	$p < 0.001$	119.9 ± 42.8	74.1 ± 43.2	$p < 0.001$	106.7 ± 42.5	67.7 ± 38.3	$p < 0.001$
Elbow flexion	89.4 ± 34.3	54.9 ± 32.8	$p < 0.001$	125.3±37.2	86.1 ± 51.2	$p < 0.001$	124.0 ± 43.6	75.7 ± 48.0	$p < 0.001$
Elbow extension	80.1 ± 26.3	56.1 ± 26.8	$p < 0.001$	126.2 ± 34.1	83.4 ± 48.7	$p < 0.001$	110.8 ± 38.4	74.3 ± 44.4	$p < 0.001$
Wrist extension	48.7 ± 20.1	31.0 ± 17.9	$p < 0.001$	73.2 ± 27.6	42.2 ± 31.1	$p < 0.001$	65.0 ± 27.7	38.5 ± 27.8	$p < 0.001$

Table 3. Effect sizes for comparisons of muscular force in non-paretic and paretic upper limb. The results are displayed as Cohen's *d* and 95% confidence interval

Movement	Female		Male		Total	
	Cohen's *d*	95% CI	Cohen's *d*	95% CI	Cohen's *d*	95% CI
Shoulder flexion	1.4	0.7–2.1	1.2	0.7–1.7	1.2	0.8–1.6
Shoulder abduction	1.1	0.4–1.7	1.2	0.7–1.6	1.1	0.7–1.5
Shoulder extension	1.3	0.6–2.0	1.3	0.8–1.7	1.2	0.8–1.5
Shoulder rotation ext.	1.1	0.5–1.8	1.3	0.8–1.8	1.2	0.8–1.6
Shoulder rotation int.	1.0	0.4–1.7	1.1	0.6–1.5	1.0	0.6–1.3
Elbow flexion	1.0	0.4–1.7	1.2	0.8–1.7	1.1	0.7–1.4
Elbow extension	0.9	0.2–1.5	1.0	0.5–1.5	0.9	0.5–1.3
Wrist extension	0.9	0.3–1.6	1.1	0.6–1.5	1.0	0.6–1.3

Table 4. Correlation coefficients for differences in muscular force in non-paretic (non-A) and paretic upper limb (A) versus RMA results. The computations are displayed as Spearman's rho correlation coefficients (ρ) and p-value

Movement	Female		Male		Total	
	ρ	p	ρ	p	ρ	p
Shoulder flexion	0.18	$p = 0.443$	–0.19	$p = 0.235$	–0.08	$p = 0.573$
Shoulder abduction	–0.04	$p = 0.862$	0.16	$p = 0.340$	0.04	$p = 0.760$
Shoulder extension	–0.04	$p = 0.854$	–0.09	$p = 0.565$	–0.10	$p = 0.453$
Shoulder rotation ext.	–0.01	$p = 0.977$	–0.19	$p = 0.248$	–0.15	$p = 0.238$
Shoulder rotation int.	–0.45	$p = 0.045$	–0.15	$p = 0.353$	–0.22	p = 0.088
Elbow flexion	0.13	$p = 0.583$	0.11	$p = 0.585$	0.06	p = 0.656
Elbow extension	–0.13	$p = 0.585$	–0.13	$p = 0.432$	–0.14	p = 0.270
Wrist extension	–0.11	$p = 0.646$	–0.11	$p = 0.490$	–0.14	p = 0.292

movements, and all verbal encouragements were standardized. Prior to data collection, demonstration and familiarization trials of all procedures were allowed [20]. Then, the subjects were asked to perform a maximal isometric force against the dynamometer during five seconds and the peak values were recorded. Extremity positions and dynamometer placement during the testing of specific muscle group were taken from the methodology described by Bohannon [6]. A tester stabilized proximal part of the tested joint manually. Non-affected upper limb was tested as first. Isometric muscle force values from upper limb muscles were measured during maximum voluntary contraction (MVC) with hand-held dynamometer. All strength measurements were taken in standardized positions by one rater. The results are given in Newtons [N], mean values of muscular force (Table 2), effect sizes and confidence intervals displayed as Cohen's *d* and 95% CI were determined (Table 3). Moreover, we made the coefficients correlation for differences in muscular force versus the Rivermead Motor Assessment (RMA) arm section (Table 4). The study included acute stroke patients at their first-ever stroke exclusively, enrolled 1–2 weeks after the event onset, with ischemic lesions forms only. The diagnoses were confirmed by means of CT scan and/or MRI exam. The inclusion criteria were first ischemic stroke, at least 10 ± 5 days from the event, unilateral paresis, Mini Mental State Examination higher than 20, muscle strength in upper limb higher than 2 (movement without gravity) evaluated with Medical Research Council (MRC), absence of sensory impairment evaluated by neurological test. The exclusion criteria were as follows: patients aged less than 18 or more than 85, previous cerebrovascular disease or TBI, botulinum toxin injection within the previous 15 days from enrolment, cognitive disorders such as neglect, upper limb apraxia, and bilateral upper limb impairment.

The study was approved by the Medical Ethics Committee of the Medical of Łódź, Poland.

2.1. Statistical analysis

ANOVA without replication were used to compare the results from A and non-A groups. Moreover, we calculated the mean delta values with their confidence intervals and evaluated the changes adjusted for baseline values using covariance analysis. The effect size of the changes (*d*) is defined as the difference between the mean divided by standard deviation of either group. We considered the difference to be small when the *d* value was 0.2, moderate when *d* was approximately 0.5, and large when *d* was 0.8 or above. Spearman correlation was used to assess the relationship between muscle force and the different variables studied. All the results are presented as the mean (SD), and the limit of significance was set at $P < 0.05$ for all of the analyses.

3. Results

All the results in the covariance analysis presented as effect size changes were estimated as large difference.

Table 5. Comparison of muscular force in non-paretic (non-A) and paretic upper limb (A) in males and females after ischemic brain stroke

	Muscular strength (non-A) and (A) [%]		
	female	male	total
Shoulder flexion	41%	46%	45%
Shoulder abduction	33%	41%	39%
Shoulder extension	34%	41%	39%
Shoulder rotation ext.	37%	44%	42%
Shoulder rotation int.	32%	38%	37%
Elbow flexion	39%	31%	39%
Elbow extension	30%	34%	33%
Wrist extension	36%	42%	41%

The strength of the upper limb (A) in comparison to (non-A) was 39% weaker (Table 5). The severely affected muscle groups (see Figs. 1 and 2) were the shoulder flexion 41% (women) versus 46% (men); elbow flexion 39% (women) versus 31% (men); wrist extension 36% (women) versus 42% (men).

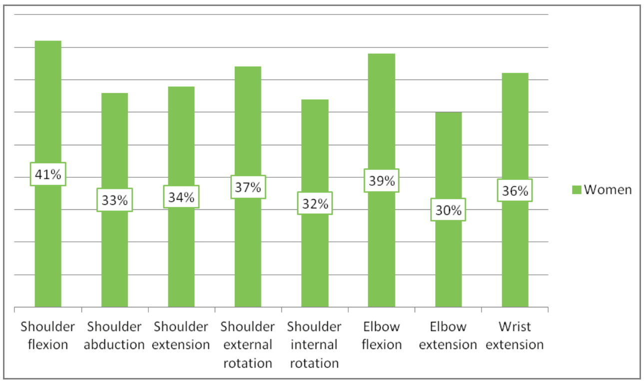

Fig. 1. Comparison of muscular force in non-paretic and paretic upper limb in women after ischemic brain stroke

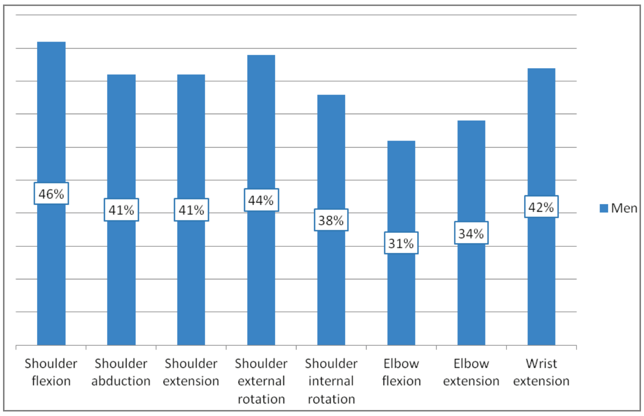

Fig. 2. Comparison of muscular force in non-paretic and paretic upper limb in men after ischemic brain stroke

Table 6. Correlation coefficients for differences in muscular force in non-paretic and paretic upper limb and RMA results versus the studied patients' age. The computations are displayed as Spearman's rho correlation coefficients (ρ) and *p*-values

Movement	Female		Male		Total	
	ρ	*p*	ρ	*p*	ρ	*p*
Shoulder flexion	–0.15	$p = 0.520$	0.12	$p = 0.457$	0.08	$p = 0.546$
Shoulder abduction	–0.02	$p = 0.921$	0.13	$p = 0.442$	0.12	$p = 0.370$
Shoulder extension	0.02	$p = 0.922$	0.21	$p = 0.190$	0.22	$p = 0.085$
Shoulder rotation ext.	0.17	$p = 0.481$	0.07	$p = 0.657$	0.19	$p = 0.144$
Shoulder rotation int.	0.18	$p = 0.445$	–0.15	$p = 0.343$	0.06	$p = 0.673$
Elbow flexion	–0.02	$p = 0.920$	0.004	$p = 0.980$	0.10	$p = 0.435$
Elbow extension	0.11	$p = 0.630$	0.07	$p = 0.684$	0.15	$p = 0.263$
Wrist extension	–0.03	$p = 0.912$	0.001	$p = 0.998$	0.10	$p = 0.427$
RMA at input	–0.31	$p = 0.183$	0.03	$p = 0.864$	–0.03	$p = 0.837$
RMA at output	–0.42	$p = 0.067$	0.07	$p = 0.687$	–0.07	$p = 0.616$

In non-A the highest result was observed during extension in arm 132.7 N (102.7 N female vs. 147.7 N male, $p < 0.001$), the lowest result was in carpal extension 65.0 N (48.7 N female vs. 73.2 N male, $p < 0,001$). In (A) the highest result was observed during extension in arm 80.9 N (68.2 N female vs. 87.3 N male, $p < 0.001$), the lowest result was in carpal extension 38.5 N (31.0 N female vs. 42.2 N male, $p < 0.001$) (Table 2). A comparison of muscular force in non-paretic (non-A) and paretic upper limb (A) showed that the differences were the most significant in arm flexors (45%).The lowest deficits of muscle force were estimated in the case of elbow extension in women (30%) and in the case of elbow flexion in men (31%). Moreover, we noticed that muscle strength in post stroke upper limb (A) decreased about 39% compared to (non-A). According to the Rivermead scale part 3 (upper limb) we observed a decreased level of functional status in upper limb (A) in relation to non-A (Table 6).

4. Discussion

Our results demonstrate that strength of the muscles of contralateral side to the brain lesion was impaired in relation to ipsilateral side in all muscle groups studied. We comprehensively assessed the muscle force within the major joints of the upper limb (shoulder: flexors, extensors, abductors, internal and external rotators; elbow flexors and extensors as well as wrist extensors). We have found some articles on the deficits or distribution of muscle strength of the upper limb in hemiparetic patients [3], [4], [8], [10], [11], [13], [18], [27], [28], but their assessment usually included fewer muscle groups. Very few studies have assessed a contribution of muscle strength deficits in many groups of upper limb muscles. Only Bohannon and Smith [8], Dewald and Beer [13] also evaluated similar to our muscles especially in relation to the shoulder, but in the first study, only distribution of weakness was assessed without distribution of absolute muscle strength of upper limb.

In our study, the strongest muscles of upper limb were the extensors of shoulder both in ipsilateral and contralateral sides to the lesion (Table 2), followed by the flexors of the elbow. The weakest muscles proved to be the extensors of the wrist. These results are in line with those obtained in healthy participants [4] but not always with those concerning stroke patients [13]. In Dewald and Beer study [13], the flexors of the shoulder of paretic side and the non-paretic flexors of the elbow both in men and women proved to be the strongest muscle group, while the extensors of the shoulder were almost the weakest muscles from those studied. However, these authors did not analyze the force of the wrist extensor muscles. The differences result from the different methods of testing, especially from different starting position of individual muscles presented in our and Dewald and Beer [13] studies. Using different measuring devices (in our study, hand-held dynamometer was used, whereas in Dewald and Beer [13] – static device) should not have much impact on the result due to the established validity and reliability of hand-held dynamometers [22], [25]. However, the starting position could be crucial. It is known that changes in muscle length and the joint angle can affect muscle activation and strength [6]. Additionally, abnormal synergies in the paretic shoulder and elbow of hemiparetic subjects [17] could produce different results of muscle force for various starting positions. For example, starting position in various levels of shoulder abduction affects torque of elbow flexion and extension torque – with increasing shoulder abduction torque level, elbow flexion strength increased and elbow extension force decreased [5].

The weakest muscles in our patients and in other studies (from muscles analyzed in our study) were wrist extensors in healthy participants [4], post stroke patients [11] as well as in patients with muscular deficits due to diseases of peripheral origin [28]. It was not surprising for us because wrist extensor muscles are smaller than proximal muscle groups of upper limb, and it is generally known that muscle force is determined by cross-sectional area [2].

More studies on the difference in muscular strength after stroke refer to the elbow muscles. In our and every other analysis, absolute force of flexors is greater than that of extensors, both in paretic and non-paretic limb, but not in all studies the difference reaches the level of statistical significance or this relationship has not been studied [3], [13], [27], [28].

The more interesting problem is magnitude and distribution of muscle weakness after stroke. Average force of affected upper limb in comparison to non-affected was 39% (35% women, 40% men) weaker. The result is lower than deficits (measured with the same methodology and the same muscle groups) in Bohannon and Smith study [8] – 65% (58.3–72.9%) in initial measurement and closer to our results on patient's discharge – 45% (37.9–54.1%), but we included to our study patients with muscle strength at least with 2nd degree of Medical Research Council (MRC) Scale. The three most severely affected muscle groups in relation to stronger side were the shoulder flexors (45%), shoulder external rotators (42%), wrist extensors (41%) and the least affected – elbow extensors (33%) (Fig. 3), whereas in Bohannon and Smith initial study [8], the most affected were wrist extensors (72.9%), elbow flexors (70.5%) an shoulder external rotators (69.6%), the least affected shoulder medial rotators (58.3%). The patterns of muscle weakness are a bit different in our and in Bohannon and Smith study. There are also differences in the measurements performed at different times (initially and after rehabilitation period). Colebath and Gandevia [11] emphasize that distribution of muscle weakness was not the same in all patients studied, nor was any single muscle group always most severely affected.

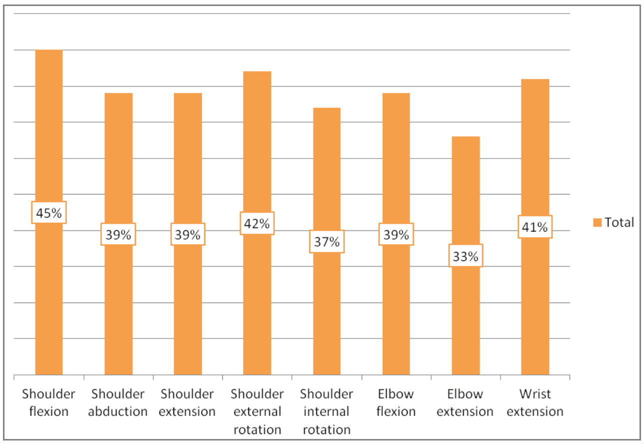

Fig. 3. Comparison of muscular force in health and paretic upper limb after ischemic brain stroke

Out of antagonistic muscle groups, shoulder flexors were more affected than extensors ($p < 0.001$), shoulder external rotators were more affected than internal rotators ($p < 0.001$) and elbow flexors more than extensors (statistically not significant), both in men and women. These patterns were generally the same as in Bohannon and Smith study [8], but differ significantly (from antagonists) only in relation to shoulder internal and external rotators. In turn, Colebatch et al. [10] reported that elbow flexors are stronger than extensors, but the elbow flexors rather than the extensors were relatively more weakened. In the next study of Mercier and Bourbonnais [18], flexors seem to be (on average) more weakened than extensors, but these differences did not reach statistical significance.

Generally, men (Fig. 2) show more significant decrease of strength than women (40% vs. 35%, statistically not significant). It is difficult to explain these results. Schaefer et al. [23] suggested that motor deficits following stroke vary with the side of lesion. In women more commonly occurred left-side hemiparesis (right hemisphere lesion – 65% vs. 50% in men). According to this study [23] right-hemisphere lesion produced deficits in final position accuracy – it is possible that these abnormalities affect the possibility of developing strength during the measurement.

It was surprising for us that no significant correlations were found between muscle strength results and functional status. The findings of many studies have shown muscle strength as an important determinant of functional capacity [7], [18], [21], [29]. Only one test (the Rivermead Motor Assessment – RMA – arm section) was used in our study to describe hand function after stroke. Mercier and Bourbonnais [18] in their research used four tests and not all the results of muscle force were correlated with the results of functional tests. Maybe in the future, studies should consider a broader assessment of the performance of the upper limb.

5. Conclusions

Muscle force of upper limb (A) a short time after stroke demonstrates a 39% decrease. Men show more significant decrease than women (40% vs. 35%). Functional assessment in RMA values show the better results in women (4.9 ± 4.1) than men (3.4 ± 3.2).

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