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Force analysis of shoulder joint muscles in the early phase of brain stroke

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Purpose: Upper limb impairment in the early phase of brain stroke is one of the key problems in rehabilitation. An estimation of muscle force can be a helpful factor for functional improvement after a stroke. The primary goals of this study were to determine the muscles with the lowest force in the affected (A) and non-affected (non-A) upper limb. Moreover, the differences between men and women were compared and these values were correlated with age. *Methods:* One hundred (n = 35 female, n = 65 male) post-stroke patients met the inclusion criteria. The mean age of the study participants was 66.1 years. Muscle force for external and internal rotators of shoulder was measured with handheld dynamometer. Moreover, the correlation coefficients for differences in muscular force with the patient's age were estimated. *Results:* Our study reports that the force of the (A) side in relation to the (non-A) was by 37% weaker. We observed about a 40% decrease in the force of the shoulder's external rotation (female – 42%; male – 41%) and shoulder's flexion (by 38% – female; 40% – male). Significant correlations between the muscle force and the age of post-stroke patients were also found. It was concluded that about 4 weeks after the first stroke in the patient's life, the external rotators are the most affected group of shoulder muscles. *Conclusions:* Neither sex nor the side of the ischemic brain injury influence the muscle force, whereas age determines both muscle force and muscle force deficits. Older post-stroke patients demonstrate fewer deficits in muscle strength than younger ones.

Key words: *muscle force, upper limb, shoulder joint, stroke, dynamometer*

1. Introduction

Stroke is one of the leading causes of long-term disability and one of the key problems in rehabilitation [2]. The number of individuals who experience a stroke increases with age. One of the most common symptoms of stroke is gradually progressing pain from a hemiplegic shoulder that can delay functional recovery. Clinical studies report that the affected shoulder pain occurs as early as 2 months post-stroke. Post-stroke shoulder pain occurs in about 30% of individuals [8]. The precise etiology of shoulder pain is not established. However, some of the suspected factors involved in shoulder pain include rotator cuff injury as well as muscle imbalance of the glenohumeral joint [24]. Information presented in another study suggests that there are three main functional after-effects of stroke on the upper limb, such as learned nonuse, learned bad-use and forgetting. The author shows that factors such as weakness, paresis, sensory impairment and immobility lead to learned nonuse [27]. Post-stroke shoulder pain occurs very often. This pain can lead to learned nonuse and contribute to functional disorder [27]. A major aim of stroke rehabilitation is optimization of the recovery of muscle strength to regain the ability to care for one's self. Reduction in muscle strength (ability to generate force) is the main reason limiting functional performance [24] and quality of life [16]. The changes in muscle force after stroke depend not only on the location and volume of the brain injury, but also on the age of patients and their general condition. Although there are very little clinical studies about selective

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analysis of individual muscles affected following a stroke, most studies support the clinical observation that distal muscles of the paretic side have greater force deficits, compared to proximal muscles. An estimation of muscle force can be a helpful factor for functional improvements after a stroke [20]. Knowledge about the weaker muscles is critical in creating a long-term rehabilitation program. Post-stroke decrease of muscle force was shown in different studies comparing the ipsilateral limb to the control group [24]. Muscle force between muscle groups (e.g., flexors/extensors) and joints (proximal/distal) stay incompatible after strokes [15]. Resolution for muscle force between antagonistic muscle groups is different in new studies [26]. For example, Dewald et al. [9] showed that the muscle force of shoulder flexors in hemiparetic patients is superior to extensors. On the other hand, our previous studies showed that shoulder extensors in healthy and affected upper limbs were slightly stronger than shoulder flexors [30].

Various factors can modify muscle weakness after a stroke. Aging is associated with a number of changes related both to the muscular and nervous system as well as changes in the motor unit's structure and functioning. There are reports with different results referring to strength training and detraining effects after this exercise program [14], different characteristics of muscle fibers [25], and different muscle activation strategies during fatiguing contractions [18] in men and women. Finally, it is known that differences in motor control depend on the brain hemisphere [22], [29]. That is why we suspect that muscle weakness after stroke might be affected by these factors (age, sex, brain lesion side).

The most common method of estimating muscle strength in patients after stroke is the peak or average result of torque during isometric or isokinetic contractions. These measures have been shown to be reliable [3], [10].

Currently, hand-held dynamometers are becoming more and more popular in rehabilitation. This is the alternative method of measuring muscle force in which reliability has been established for individuals with stroke [3]. Therefore, our clinical study was designed to assess the force of shoulder muscles in patients after their first stroke to indicate the weakest points and optimize rehabilitation programs in the future. We have set the following objectives: first, to point out the weakest muscles of the shoulder in both affected and non-affected sides; next, to evaluate the differences between genders as well as between patients suffering from a brain injury on the opposite side; finally, to correlate these values with age.

To our knowledge, this is the first study assessing differences in muscle strength deficits in patients after a stroke depending on various factors like age, sex, and the side of the brain injury lesion.

2. Materials and methods

From 155 patients that had an ischemic stroke for the first time in their life, 100 patients (35 women; 65 men), who met the inclusion criteria, were enrolled (Fig. 1). To provide data for a subsequent sample size calculation we required at least 100 early stroke patients to estimate parameters of interest [19]. In order to provide some assurance that our sample size would provide sufficient data for a power calculation, we analyzed similar clinical studies [10], [20]. All patients were hospitalized in the Neurorehabilitation Ward in III General Hospital in Lodz, Poland. The mean age of the study participants was 66.1 (SD = 8.8) years, though the examined women were statistically significantly older than the men, i.e., 70.4 (SD = 8.4) years (women) and 63.8 (SD = 9.1) years (men). Among the qualified women there were 11 with right paresis side and 24 with left paresis side, in the case of men, the numbers were 34 and 31, respectively. Muscle force is defined as "the maximum voluntary force that a subject was able to exert on the dynamometer under specific testing conditions'' [4]. Muscle force of the shoulder joint was measured using a MicroFet 2 handheld dynamometer (Hoggan Health Industries, UT, USA). Extremity positions and dynamometer placement during the testing were according to Bohannon [4]. Correct positioning and stabilization was provided to avoid compensatory movements and to achieve maximum isolation of movement. Furthermore, all verbal encouragements were standardized. Next, a tester stabilized the proximal part (shoulder blade) of the tested joint manually. The healthy side was tested first. Afterwards, the subjects were asked to perform a maximal isometric force (maximum voluntary contraction – MVC) against the dynamometer lasting four seconds. Then, the peak values were recorded. The mean values of muscular force are displayed in newtons [N], along with effect sizes and confidence intervals. The correlation coefficients represent the differences in muscular force versus the patient's age. The inclusion criteria were similar to those in our previous study [30]: first ischemic stroke in the first month from event, unilateral paresis, MMSE higher than 20, muscle force of shoulder joint muscle higher than 2 estimated with Medical Research

Council (MRC), and default of sensory impairment evaluated by neurological test. The exclusion criteria were as follows: patients aged less than 50 or more than 85 years old, previous cerebrovascular disease, botulinum toxin injection within the previous 15 days from registration, cognitive disorders, upper limb apraxia, bilateral upper limb impairment, history of arm arthritis and lack of verbal and logical contact with the patient. Written informed consent was obtained from each subject. The Medical Ethics Committee of the Medical University in Lodz, Poland approved the study.

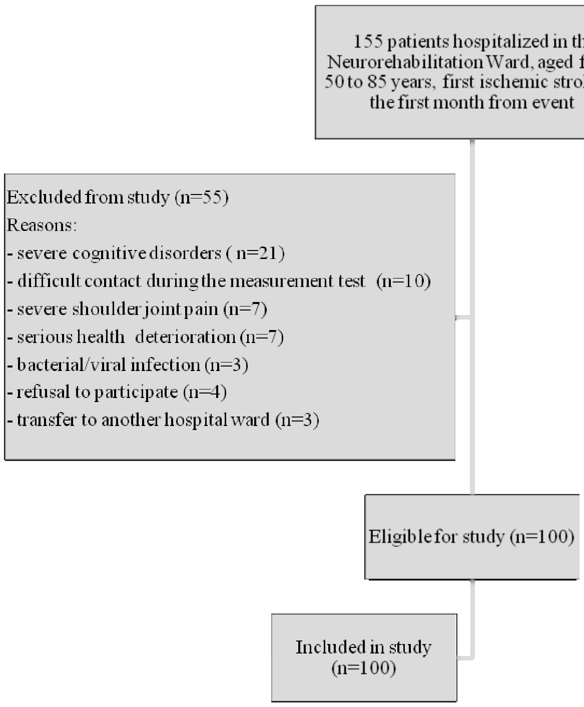

Fig. 1. Flow diagram of patient recruitment

2.1. Statistical analysis

The results from A and non-A groups were compared using ANOVA without replication. Moreover, the mean delta values with their confidence intervals were calculated. The effect size of the changes (d) was defined as the difference between the mean divided by standard deviation of either group. We observed a small difference when d was 0.2, a moderate difference when d was roughly 0.5, and a large difference when d was 0.8 or above. A Spearman correlation was used to rate 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 analyses.

3. Results

Both left and right upper limbs paresis resulted in statistically significant differences ($p < 0.001$) in muscular force of the shoulder between (non-A) and (A) sides of the body (Table 1) as well as in males and females (Table 2). Force analysis of shoulder joint muscles showed significant differences between the (A) upper extremity (i.e., the shoulder) versus the (non-A) one – in the examined patients altogether, as well as in the gender split groups (Table 3). The force of the (A) side in comparison with the (non-A) was by 37% weaker. The severely affected areas were (Fig. 2) the shoulder external rotation in 42% of females and 41% of males and the shoulder flexion in 38% of females and 40% of males (Table 3). The greatest muscle force values were measured during the non-affected shoulder extension – 125.2 N overall, 90.1 N in women, and 144.0 N in men ($p < 0.001$). The lowest muscle force values were appraised during the paretic shoulder external rotation – 48.6 N overall, 35.4 N in women, and 55.8 N in men ($p < 0.001$) (Table 2). The results are graphically presented (Fig. 3). We found correlation between muscle force and age in the non-affected side but no in the affected side (Table 4). The greatest relative loss of force in the (A) versus (non-A) shoulder was observed with reference to external rotation of the shoulder – 41%. The smallest

Table 1. Differences in muscular force deficits between the left and right upper limb of post-stroke paresis affected (A) versus non-affected (non-A). The results are displayed in newtons [N] as the mean value and the standard deviation

Movement of shoulder	Left upper limb (n = 55)			Right upper limb (n = 45)			Total (n = 100)		
	non-A [N]	A [N]	p	non-A [N]	A [N]	p	non-A [N]	A [N]	p
Flexion	88.2 44.6	52.5 34.4	<0.001	108.5 47.1	66.0 43.0	<0.001	97.3 44.6	58.6 38.9	<0.001
Abduction	87.5 35.9	56.4 37.9	<0.001	106.8 39.6	72.1 39.5	<0.001	96.2 38.6	63.5 39.2	<0.001
Extension	115.4 46.9	74.9 42.4	<0.001	137.0 53.8	93.2 54.5	<0.001	125.2 51.1	83.1 48.8	<0.001
Ext. rotation	76.2 36.6	45.5 33.5	<0.001	88.8 35.5	52.5 31.9	<0.001	81.9 36.5	48.6 32.8	<0.001
Int. rotation	94.05 45.5	63.5 43.0	<0.001	113.7 51.3	74.2 45.4	<0.001	102.9 49.0	68.3 44.2	<0.001

Table 2. Evaluation of muscles force in non-affected (non-A) and affected (A) upper limbs of post-stroke males and females displayed in newtons [N]

Movement of shoulder	Female (n = 35)			Male (n = 65)			Total (n = 100)		
	Non-A [N]	A [N]	p	Non-A [N]	A[N]	p	Non-A [N]	A [N]	p
Flexion	75.8 34.0	47.5 28.3	<0.001	108.9 45.5	64.6 42.6	<0.001	97.3 44.6	58.6 38.9	<0.001
Abduction	71.8 27.6	48.1 29.6	<0.001	109.3 37.5	71.7 41.4	<0.001	96.2 38.6	63.5 39.2	<0.001
Extension	90.1 34.8	61.9 28.8	<0.001	144.0 48.5	94.6 53.5	<0.001	125.2 51.1	83.1 48.8	<0.001
Ext. rotation	58.6 26.6	35.4 23.5	<0.001	94.4 35.0	55.8 35.0	<0.001	81.9 36.5	48.6 32.8	<0.001
Int. rotation	68.4 30.4	46.7 25.8	<0.001	121.4 47.1	79.9 47.7	<0.001	102.9 49.0	68.3 44.2	<0.001

Table 3. Comparison of changes in force of shoulder muscles in non-affected (non-A) and affected (A) post-stroke patients. The results are presented in percent [%]. Effect sizes for comparisons of muscular force in non-affected (non-A) and affected (A) upper limb. The results are displayed as Cohen's d and 95% confidence interval

Movement of shoulder	Female (n = 35)					Male (n = 65)					Total (n = 100)				
	Cohen's d	95% CI	Left [%]	Right [%]	Total [%]	Cohen's d	95% CI	Left [%]	Right [%]	Total [%]	Cohen's d	95% CI	Left [%]	Right [%]	Total [%]
Flexion	0.9	0.4–1.4	42	29	38	1.0	0.6–1.4	40	40	40	0.9	0.6–1.2	41	37	39
Abduction	0.8	0.3–1.3	39	29	36	1.0	0.6–1.3	37	34	35	0.8	0.6–1.1	38	33	35
Extension	0.9	0.4–1.4	33	25	31	1.0	0.6–1.6	37	33	35	0.8	0.6–1.1	36	31	34
Ext. rotation	0.9	0.4–1.4	42	43	42	1.1	0.7–1.5	44	39	41	1.0	0.7–1.3	43	40	41
Int. rotation	0.8	0.3–1.3	34	26	31	0.9	0.5–1.2	36	35	35	0.7	0.5–1.0	35	32	34

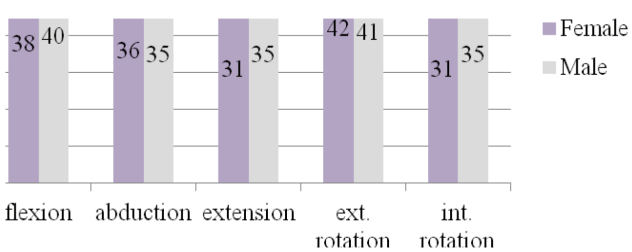

Fig. 2. Comparison of changes in force of shoulder muscles in non-affected (non-A) and affected (A) post-stroke patients. The results are presented in percent [%]

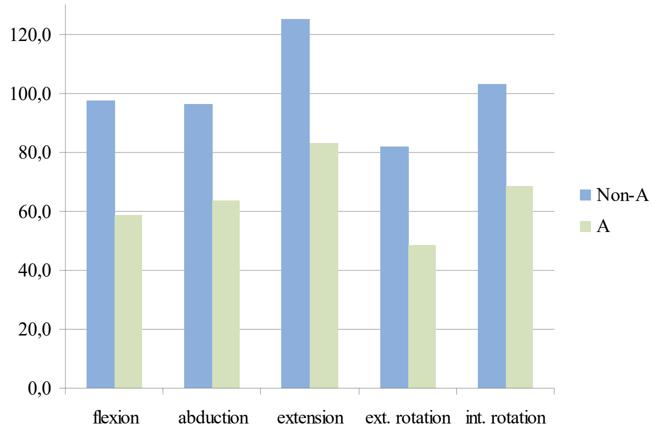

Fig. 3. Muscle force values (total) in the shoulder joint musles. The results are presented in newtons [N]

Table 4. Correlation between values of shoulder muscles force and patient's age. The computations are displayed as Spearman's ρ correlation coefficients (ρ) and p-values

Movement of shoulder	Affected (A) upper limb						Non-affected (non-A) upper limb					
	Left (n = 55)		Right (n = 45)		Total (n = 100)		Left (n = 45)		Right (n = 55)		Total (n = 100)	
	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p	ρ	p
Flexion	–0.09	0.507	–0.07	0.651	–0.13	0.196	–0.32	0.019	–0.23	0.123	–0.34	<0.001
Abduction	–0.15	0.279	–0.01	0.929	–0.14	0.170	–0.42	0.002	–0.15	0.334	–0.35	<0.001
Extension	–0.06	0.662	–0.10	0.516	–0.12	0.236	–0.29	0.032	–0.20	0.191	–0.31	0.002
Ext. rotation	–0.11	0.411	–0.06	0.675	–0.12	0.240	–0.36	0.006	–0.12	0.445	–0.31	0.002
Int. rotation	–0.22	0.102	–0.02	0.909	–0.18	0.066	–0.31	0.021	–0.14	0.355	–0.29	0.003

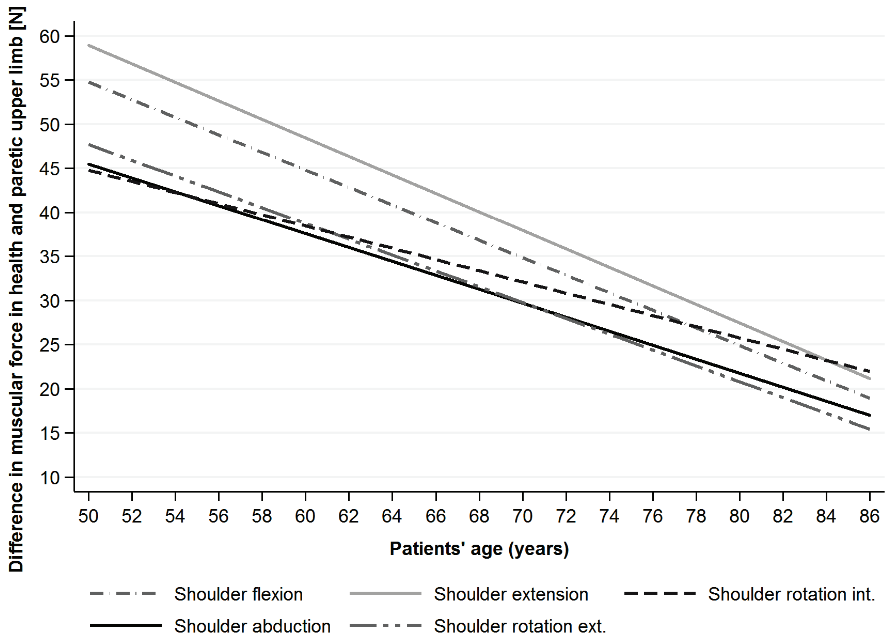

Fig. 4. Differences between the muscle force in the affected and non-affected shoulder joint and the studied patient's age (for shoulder flexion: $\rho = -0.18$, $p = 0.073$; for shoulder abduction: $\rho = -0.21$, $p = 0.035$, for shoulder extension: $\rho = -0.21$, $p = 0.041$, for shoulder external rotation: $\rho = -0.27$, $p = 0.007$, for shoulder internal rotation: $\rho = -0.16$, $p = 0.122$)

relative force loss occurred in the shoulder extensions – 34%. The force losses were similar (i.e., without statistically significant differences) both in the case of the female and the male study subjects. We found correlation between muscle force and age in the non--affected side but no in the affected side (Table 4). In order to find interesting correlations, differences between the muscle force in the affected and the non-affected shoulder joint and the studied patient's age were computed (Fig. 4). We noted a negative correlation – greater deficits in muscle force were obtained in younger patients.

4. Discussion

Shoulder muscles are very important for both stability and mobility of the glenohumeral joint [11] and it is known that they may contribute to shoulder dislocation and stability [11], [23]. Proper shoulder function is very important for effective hand function. It is known that after a stroke patients' shoulder muscle strength of the contralateral side to the brain lesion is impaired in relation to the ipsilateral. Patterns of this impairment were different for various pairs of antagonistic muscles. Adey-Wakeling et al. [1] have shown that the frequency of post-stroke hemiplegic shoulder pain is over 29% in a 12-month follow-up observation period. One of the most suspected factors involved in shoulder pain is muscle imbalance around the glenohumeral joint. Therefore, our study was trying to identify the weakest groups within the shoulder muscles. Our study indicates that the most affected muscle group was external shoulder rotators in both men and women. They were weaker than muscles on the unaffected side by 41% (effect size 1.0), while internal rotators were weaker by 34% (effect size 0.7; the least affected muscles). Similarly, in two other studies [5], [9], external rotators were the most affected group from all shoulder muscles tested. Moreover, those deficits were much more higher than in our patients. This fact might be the key to balancing the shoulder muscles. This is essential considering the external rotators are responsible for substantial anterior dynamic stability to the glenohumeral joint. Paralysis of the rotator cuff muscles (external rotators) causes that humeral head to not be well stabilized [21]. The muscle force deficits of the second antagonistic muscle groups (flexors-extensors) were smaller (flexors – 39%, extensors – 34%) and we noted that extensors are not more affected than flexors, contrary to popular belief. Similarly, Mercier et al. [24] did not show a tendency for the extensor muscles to be more affected than the flexors. We also assessed whether factors like sex, age and side of ischemia can also affect deficits of muscle strength. Several authors point out the gender-dependent differences in the structure and functioning of the muscles [14], [18], [25], [28]. Mercier et al. [24] suggest that men and women might use different neuromuscular control strategies in the upper limb (shoulder position sense, as part of the neuromuscular control system). In a study by Reid et al. [28], mobility-limited elderly men presented greater impairments in muscle function compared to women. Their studies have also shown that women with reduced mobility have the ability to maintain and preserve the intrinsic quality of single muscle fibers and cross sectional area of type IIA fibers (characterized by high force production) better than men. That is why we suspected that muscle strength deficits could differ between men and women. Men were generally stronger than women in our and other research, probably because of greater lean body mass and larger mean fiber area [25]. However, we have not observed significant differences in strength deficits between these two groups, so our suspicions were not confirmed. Only patients in the first month from stroke event were included in this study. This could potentially be too soon after a stroke to observe muscle weakness based on the mentioned mechanisms.

It is known that differences in motor control depend on brain hemisphere [22], [29]. According to some authors, right hemisphere damage (but not left) produces deficits in stabilizing the limb at the end of movement and results in significantly larger errors in final position [22]. Muscle force measurement methodology used in our study required subjects not only to maintain position, but also to generate force in the final position. Moreover, muscles of the right side are generally stronger than of the left in healthy people [13]. Consequently, basic muscle strength could also determine differences in muscle strength after stroke. Therefore, we expected that left hemiplegia (lesion of right side of brain) could be connected with greater muscle force deficits. However, our assumptions, in this case, were also not confirmed. We have noted no differences in muscle strength deficits in relation to the brain lesions side. We observed that age determines muscle strength, but only in the non-affected side. Age-related loss of muscle mass and, as a consequence, muscle strength and muscle function is a known phenomenon called sarcopenia. Sarcopenia is very common in the elderly population and is associated with many adverse effects [17]. We did not observe dependency between age and muscular strength in the affected limbs. It is possible that stroke or the accumulated effect of stroke and aging determines the level of muscle strength to a greater extent than age only.

Our findings also show that not only muscle strength, but also deficits in muscle strength in relation to the unaffected side, were age-dependent in most of the tested muscle groups (3 of 5 and for shoulder flexors – tendency to statistical significance). We also noted a negative correlation – greater deficits in muscle force were obtained in younger patients. We suspect that this is connected with age-related reduction of brain lateralization. This phenomenon (model HAROLD – hemispheric asymmetry reduction in older adults) is well described for cognitive function [6], but it is presumed that it may also apply to motor function. Calautti et al. [7] have found that in perfusion positron emission tomography (PET), during simple tasks like thumb-to-index tapping, as expected, activated the contralateral hemisphere in young and older adults, but in older adults, significantly greater activation of the ipsilateral hemisphere during hand tapping was demonstrated than in younger participants. Similar results were obtained in another study during two repetitive motor tasks during f-MRI [12]. Asymmetry reduction in older brains may reflect compensatory processes related to changes in brain function due to aging [6]. In older patients, stroke-related damage to the brain is not as severe as in younger ones due to the fact that both hemispheres' control of many brain functions is more efficient. A limitation of the present study was that the muscle force of shoulder muscles joint was not compared to muscle force of healthy patients but to the non-affected side (right or left). The results of many studies confirm that muscles force deficits may also be present in non-affected side. Therefore, the apparent differences in muscle force could be greater. Hand-held dynamometer is less perfect than stationary equipment but in the other side the use of handheld dynamometer has many advantages over static dynamometers, such as lower cost, ease of transport, the possibility of engaging a number of muscle groups. A strength of the study is that it included 100 participants, which can be considered a sufficiently large number when the reliability of measurements is evaluated.

5. Conclusions

External rotators were the most affected group from all shoulder muscles in post-stroke patients. It might be one of the most important reasons for post-stroke shoulder pain. Sex and the side ischemic of brain injury did not affect deficits of muscle strength in this group of patients, whereas age determined muscle force deficits. Older patients demonstrated fewer deficits in muscle strength after stroke than the younger ones.

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Conflict of interest

The authors declare no conflicts of interest.

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