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Objective measurements of muscle force in a group of after-stroke patients with hemiparesis

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The aim of this study was to estimate the strength of spastic muscles using Biodex System 3 within a group of patients with hemiparesis in after-stroke population.

Measurements of the moments of force in elbow flexors and extensors of both spastic and non-spastic limbs were conducted under isostatic conditions. We analysed the values obtained for both limbs in order to determine the spasticity level on an Ashworth scale (0–4). The subjects were 10 patients with hemiparesis and varying spasticity selected from an after-stroke population.

The analysis showed that spastic muscles activated less force than non-spastic muscles of the same patient. Furthermore, in a spastic limb, higher values of force were noted in the flexors than in the extensors of the elbow. In a non-spastic limb, the values of force were higher in the extensors of the elbow joint than in flexors. It is worth adding that the dynamics of force exposure, defined by a gradient of force, was much lower in spastic muscles than in non-spastic ones. Objective estimation of muscle force can be done by measuring the moments of force in particular groups of muscles upon the isokinetic contraction appearing. The repeatability of measurements may enable the kind of kinesitherapy to be determined as well as the assessment of the effectiveness of exercises in regard to force increase and dynamics of spastic muscles.

Key words: hemiparesis, spasticity, muscle force, moment of force

1. Introduction

Spasticity is one of the main symptoms of the damage to the central nervous system. It occurs in after-stroke population within an early post-stroke period or intensifies within a few weeks after the brain stroke. Clinically, spastic muscles have enlarged tension at rest, increased tendinous reflexes, increased resistivity throughout passive motions. Stereotypes of abnormal motions appear, lacking in smoothness and continuity of motion. The balance between antagonists and agonists is perturbed during arbitrary motion.

Clinical scales of spasticity, the Ashworth scale being the most popular, are used to distinguish resistivity levels of muscles during a passive motion in joint. Unfortunately, on the basis of clinical tests, we cannot estimate the force of spastic muscles. Research conducted by BOHANNON [3], IBRAHIM et al. [6], FELLOWS et al. [5], PISANO et al. [12] or PANDYAN et al. [10] concerned electromyographic records, biomechanical parameters and spastic muscles' resistivity during a passive motion under isokinetic conditions. Although some objective measurements of change of tension were made and the above parameters analysed, spastic muscle force was not estimated as yet.

When a muscle is stimulated, its tension rises. Under static conditions (isometric contraction), a change of muscle tension is followed by a change of muscle activity in its attachments, but not by a change of its length. Upon stimulation, the muscle force is activated, which is defined as the moment of force. Values of the moment of muscle force vary with time. First, they rise smoothly up to the maximum value. Maximum values are obtained after each motoric unit of the muscle has been stimulated and has stayed in that condition for a short period of time. Then, a rapid drop in those values is observed. Analysing the torque variability with time, we can find values of the gradient of force. We can determine the relation between

the ability of muscle and speed of the force exposure. Under isostatic conditions, measurements of the moment of force in patient's spastic and non-spastic muscles allow us to compare the dynamics of reaching the maximum torque in muscles as well as to estimate objectively the force in spastic muscles.

2. Materials and methods

We measured the values of torque (M) in the elbow joint under isostatic conditions for the extensors (M_{EE}) and the flexors (M_{FE}) during the maximal voluntary isometric contraction (MVC). Measurements were conducted in a group of 10 patients (8 men, 2 women), aged 50–70, with hemiparesis, from the after-stroke population. The spasticity varied within the group from 1 to 3 on the Ashworth scale. During the research all the patients declared their right limb to be more active than the left one.

Table 1. Characteristics of the group of subjects (n = 10)

Type of hemiparesis	Number of patients		Level of spasticity
Right-sided	1	6	1
Left-sided	9	2	2
		2	3

2.1. Measuring stand

We used a Biodex System 3 for the measurements of the moments of force in selected groups of muscles. We equipped it with a splint with adjustable axis of rotation which ensured stabilisation and desired angle of the upper limb. We also added a dynamometer. The main elements of the measuring system were: a chair which stabilised the trunk, a splint with measuring gauge, an amplifier, a controlling mechanism and a computer.

2.2. Method

A patient sat on the chair with a trunk stabilised with belts, the upper arm being in indirect position and a forearm, also in indirect position, being flexed in the elbow joint at an angle of 90°. The dynamometer lever was locked up in the position described above. The measurements were conducted in a sagittal plane.

Each patient did 3 repetitions of the exercise: flexing (10 s), relaxing (15 s), straightening (10 s) and relaxing (15 s). We checked spastic and non-spastic upper limbs. The measurements were performed in accordance the primary research conducted.

3. Results

3.1. Force (moment of force M) of spastic and non-spastic muscles

The primary research was conducted on a group of 4 patients from the after-stroke population, two of them with the level of spasticity 1 and two others with the level of spasticity 2 on the Ashworth scale. The purpose of the research was to work out appropriate methods of measurements, especially of an angle for maximum torque in isometric contraction of a group of muscles being tested, as well as the time of contraction and a pause between contractions. The results of primary research are given in Table 2.

Table 2. The moments of force in the elbow joint, obtained from the of primary research performed on the group of 4 patients

Joint	Limb	Group of muscles	Angle [°]	M_{AV} [N·m]
Elbow	non-spastic	flexors	90	**53.64**
		flexors	60	**39.69**
		flexors	15	**36.64**
Elbow	spastic	flexors	90	**13.81**
		flexors	60	**11.99**
		flexors	15	**3.97**

M_{AV} – average values from three measurements of the moments of force.

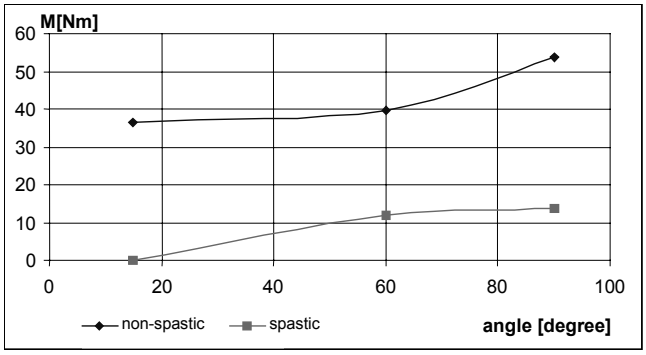

Fig. 1. The moment of force versus an angle of flexion in the elbow joint

In Table 2, we collected the averaged values of torque for the elbow flexors. The values were taken from 3 measurements of torque conducted at the mo-

ment of isometric contraction for different angles of flexion in spastic and non-spastic limbs.

The primary research showed that for flexors the *M* values were the highest at an angle of flexion of 90°. The angle of 0° indicates a full extension of the limb.

Similar measurements were performed for the extensors, the results being given in Table 3 for both the extensors and the flexors.

Table 3. The values of torque for elbow flexors and extensors

Joint	Limb	Group of muscles	Angle [°]	M_{av} [N·m]	M_{min} [N·m]	M_{max} [N·m]
Elbow	non--spastic	extensors	90	**32.5**	15.2	46.3
		flexors	90	**25.6**	10.4	50.1
Elbow	spastic	extensors	90	**21.2**	5.3	36.0
		flexors	90	**22.9**	5.5	37.4

We analysed the following indicators:

M_{FE} [Nm] – the average of maximal values of torque for elbow flexors from 3 measurements,

M_{EE} [Nm] – the average of maximal values of torque for elbow extensors from 3 measurements,

FE/*EE* – ratio of the average of maximal values of torque for elbow flexors to the average of maximal values of torque for elbow extensors ($FE/EE = M_{FE}/M_{EE}$).

In the group of patients being tested, spastic muscles activated less force than non-spastic ones. For the latter the limb force (*M*) of extensors was higher than that of flexors. However, in spastic muscles the force (*M*) was higher for flexors. In spastic muscles, the torque of extensors is much lower than in non-spastic muscles.

We also analysed the results for the group of women and the group of men (Tables 4 and 5).

Table 4. Results for the group of women ($n = 2$)

Joint	Limb	Group of muscles	Angle [°]	M_{av} [N·m]	*FE*/*EE* [–]
Elbow	non--spastic	extensors	90	**18.79**	0.69
		flexors	90	**12.89**	
Elbow	spastic	extensors	90	**16.78**	1.11
		flexors	90	**18.61**	

Table 5. Results for the group of men ($n = 8$)

Joint	Limb	Group of muscles	Angle [°]	M_{av} [N·M]	*FE*/*EE* [–]
Elbow	non--spastic	extensors	90	**36.78**	0.82
		flexors	90	**30.19**	
Elbow	spastic	extensors	90	**27.18**	1.08
		flexors	90	**29.37**	

The values of the torque for flexors and extensors of spastic and non-spastic limbs were almost twice as high for men as those for women. In the non-spastic limb, activated force was higher for extensors than for flexors, whereas in the spastic limb, activated force was higher for flexors, regardless patient's gender. Moreover, *FE*/*EE* indicator varied being still higher than 1 for spastic muscles and lower than 1 for non-spastic muscles (Table 6).

Table 6. The ratio of the maximal value of torque for flexors to the maximal value of torque for extensors in elbow joint (averaged values from 3 measurements for all patients)

Group	Number [*n*]	*FE*/*EE* [–]	
		n-s	s
Patients with hemiparesis	10	0.79	1.08

n-s – non-spastic limb.
s – spastic limb.

3.2. Muscle force and the level of spasticity

We also compared values of torque for patients with low level of spasticity – 1 on the Ashworth scale, and for patients with higher level of spasticity – 2 or 3 on the Ashworth scale. The conclusion was that the higher the level of spasticity on the Ashworth scale, the lower the force activated in muscles. Table 7 shows the values of torque for a limb with paresis and varying level of spasticity, and those for a healthy limb.

Table 7. Values of torque for varying levels of spasticity

Limb	Level of spasticity	Group of muscles	Range of values (*M*) [NM]
Non-spastic	0	flexors	13.6–37.6
		extensors	23.1–41.9
Spastic	1	flexors	17.4–33.8
		extensors	16.9–33.3
	2	flexors	10.5–28.1
		extensors	5.7–18.1
	3	flexors	5.6–5.7
		extensors	5.0–5.4

Table 8 shows the averaged values of torque for flexors and extensors and variability of *FE*/*EE* factor in relation to the clinical level of spasticity on the Ashworth scale. Flexors as well as extensors of the limb with paresis and increased muscle tension (3rd level) had significantly lower muscle activating force. It is worth noting that the ability to activate higher force in muscles of non-spastic limb was greater in patients with a higher level of spasticity than in pa-

tients with a lower level of spasticity. Figure 2 shows the relation between the force of muscles and the level of spasticity. The higher the muscle tension, the lower the force. The force of flexors was higher than the force of extensors.

Table 8. Relation between the muscle force and the level of spasticity on the Ashworth scale

Level of spasticity	Limb	M_{FE} [NM]	M_{EE} [NM]	FE/EE [–]
	healthy (non-spastic)	25.5	32.7	0.77
1	spastic	**24.9**	**24.2**	1.06
	healthy (non-spastic)	15.3	22.6	0.68
2	spastic	**20.4**	**17.4**	1.17
	healthy (non-spastic)	36.3	40.3	0.9
3	Spastic	**5.5**	**5.3**	1.04

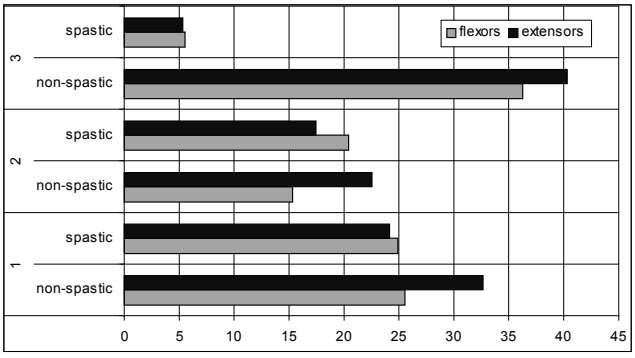

Fig. 2. Relation between the values of torque and the level of spasticity on the Ashworth scale in healthy and spastic limbs

3.3. Gradient of torque

A relation between the muscle force and the level of spasticity is not only visible in maximal values of torque, but also in curves representing the torque vs. time. We analysed the curve for the torque increment vs. time. The relation between two defined points in a time unit is a gradient of force. The gradient of force equals tgβ, where β is the angle formed by the curve representing the torque and the time axis.

$$G_M = \frac{\Delta M}{\Delta t} = k \operatorname{tg} \beta ,$$

where k = 1 Nm/s is a dimensional coefficient.

The time gradient (G_M) of torque shows the dynamics of muscle force exposure.

We determined average gradients of torque for each measurement (elbow flexors and extensors) of healthy and spastic limbs. Then, we determined average gradients of force for the three levels of spasticity (Table 9).

We also determined a gradient for Δt = 1.5 s, because the curve representing torque increment for spastic muscles was far from ideal. We chose a segment of the curve of retarded increment for the purpose of our analysis.

In spastic muscles the dynamics of the muscle force exposure was significantly lower than in non-spastic muscles. Muscles with low spasticity level (1) reached the values close to those of healthy muscles. In muscles with high spasticity level (3), this dynamics was low in both groups of flexors and extensors.

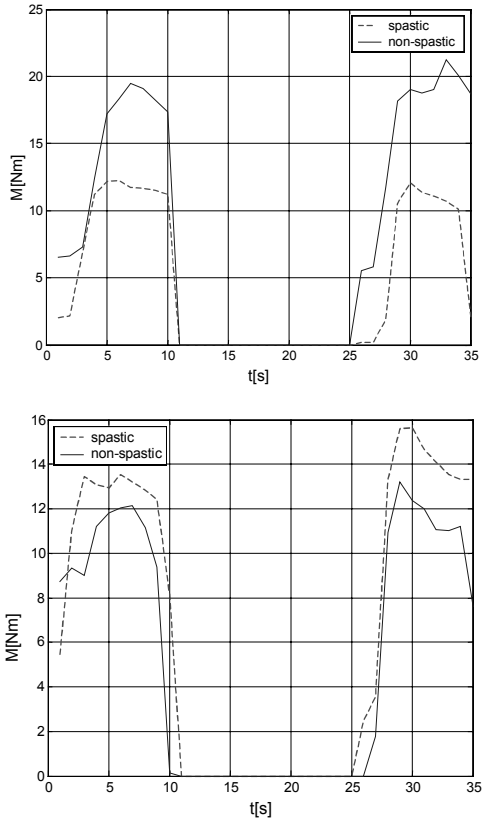

Fig. 3. Static moment of the torque of flexors and extensors with spasticity level 1 on the Ashworth scale

Table 9. Gradient of torque in relation to the level of spasticity on the Ashworth scale

Level of spasticity on Ashworth scale	Spastic		Healthy	
	Flexors tgβ	Extensors tgβ	Flexors tgβ	Extensors tgβ
1	10.20	12.54	9.12	10.83
2	6.90	8.04	7.31	9.47
3	**2.78**	**0.14**	6.00	9.49

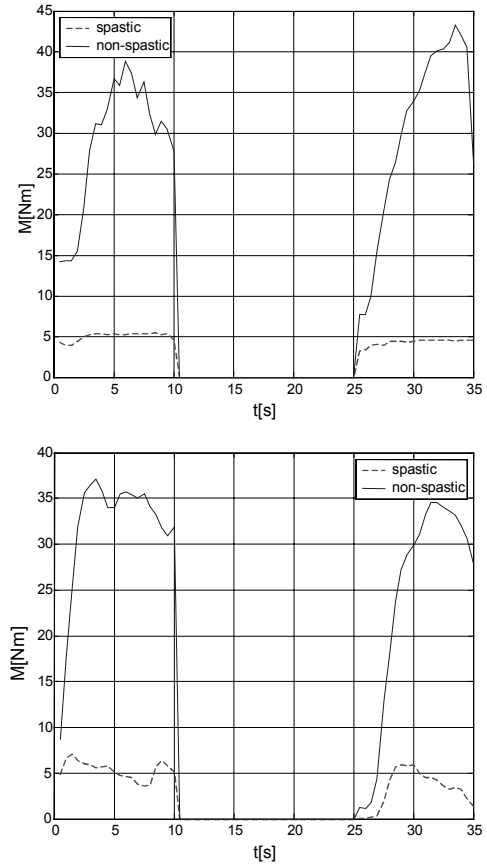

Fig. 4. Static moment of the torque of flexors and extensors with spasticity level 3 on the Ashworth scale

4. Conclusion

Clinical estimation of muscle resistivity that occurs during passive motion in a joint is the most common quality measurement of spasticity in the after-stroke population. But much more information about spastic muscles can be obtained from measurements of force and tension in muscles through the analysis of electromyographic and dynamometric indicators of biomechanical measurements. Repeatability of measurements enables us to monitor the effects of therapy as well as to indicate the direction of therapy. A measuring method requires patient's cooperation, so only those patients who can consciously do a prescribed exercise can be qualified for the procedure. To estimate the force of spastic muscles in a group of patients with hemiparesis after brain stroke, we conducted the measurements of torque for elbow flexors and extensors under isostatic conditions. The analysis showed that:

1. Spastic muscles activated much lesser force during an isometric contraction than healthy muscles of the same patient under the same measurement settings.

2. Elbow flexors in a spastic limb had greater force than elbow extensors.

3. Elbow extensors in a healthy limb were a bit predominant as compared to elbow flexors.

4. The dynamics of force exposure was significantly lower in spastic muscles than in healthy muscles.

5. The moment of force (torque) and the gradient of torque in spastic muscles depended on the level of spasticity. Higher muscle tension caused lower muscle force and lower dynamics of force exposure.

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