Original Article

J. Phys. Ther. Sci.
27: 2545–2549, 2015

Predictive factors of hypertonia in the upper extremity of chronic stroke survivors

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Abstract. [Purpose] Muscle tone is known to predict the motor function of the upper extremity within 12 months after onset in stroke survivors. The aim of this study was to investigate whether motor function of the upper extremity can predict the risk of hypertonia in chronic stroke survivors, and to analyze the correlation between the two variables to determine the predictive validity. [Subjects and Methods] Forty-three chronic stroke survivors were assessed using the Modified Ashworth Scale (MAS) for elbow flexor tone, the Fugl-Meyer assessment of the upper extremity (FM-UE), and the Action Research Arm Test (ARAT) for upper extremity motor recovery and function. [Results] Elbow flexor tone (MAS≥1^+) increased by 0.246 compared with the baseline muscle tone even at month 12 and appeared to negatively affect the motor function of the upper extremity. The cutoff value for predicting muscle tone (MAS≥1^+) was 24 for FM-UE and 15.5 for ARAT. FM-UE had the biggest impact on elbow flexor tone (MAS≥1^+), and the risk of elbow flexor hypertonia (MAS≥1^+) increased 0.764-fold for a cutoff value of FM-UE≤24 compared with a cutoff value of FM-UE>24. [Conclusion] The results show that the most important variable for predicting muscle tone of the elbow flexor in stroke survivors is the FM assessment of the upper extremity.
Key words: Hypertonia, Motor function, Stroke

(This article was submitted Apr. 13, 2015, and was accepted May 15, 2015)

INTRODUCTION

In stroke patients with upper extremity paralysis, the affected arm can remain nonfunctional even at 6 months after disease onset in 66% of the surviving stroke patients[1, 2)]. Inappropriate motor unit recruitment appearing after stroke onset reduces the motor neuron firing rate, and increased muscle tone may cause severe paralysis[3, 4)]. Limited motor function of the upper extremity, and subsequent non-use and contracture may cause changes in the mechanics and biomechanics of the muscles over time[5–7)]. Nuclear chain fibers of the muscle spindle, responsible for the changes in muscle velocity, depend on the velocity of movement and hyperexcitability during a quick passive stretch to increase the tension level more and more. In contrast, the tendon, which softens the muscle contraction and adjusts the excessive muscle tone, is unable to function normally[8)]. Excessive muscle tone may affect the gross movement patterns caused by abnormal motor control. In addition, increased muscle tone significantly correlates with the limit of upper extremity motor function[9)], reduction in daily living activities[10)], and prolonged length of hospital stay[11)]. Data obtained by the biomechanical investigation of increased muscle tone would not only identify prognostic variables of functional recovery in stroke patients, but would also be helpful for promoting self-exercise to reduce the risk of hypertonia[8)].

In addition, increased muscle tone has been identified as predicting the motor function of the upper extremity within 12 months after stroke onset[12)]. A study of the correlation between recovery and increased muscle tone of the upper extremity in stroke patients suggested that the patients whose motor function of the upper extremity became relatively weaker within 48 hours after stroke onset would be 12.8 times more likely to experience hypertonia within 6 months than the patients with normal motor function[8)]. In addition, the patients with severe arm paresis were >10 times more likely within a month[13)], and >22 times more likely within a year post-stroke to experience hypertonicity[10)]. Our previous study defined muscle tone as the degree of resistance during passive movement in 8 different directions[13)]. However, this definition is too limited to determine in which muscle the hypertonicity might occur, and would have influenced the external validity of the study because patients without paralysis and patients with severely limited motor function of up-

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per extremity were included as study subjects. Furthermore, a 1 year follow-up study of stroke patients demonstrated the difficulty of predicting the risk of hypertonicity and identifying the patients whose hypertonicity could be prevented[10].

Earlier prospective studies targeted chronic-stroke patients with disability from stroke for more than 12 months who showed little recovery of motor function. Their findings were limited because the relationship between the motor function of the upper extremity and muscle tone was unclear. In addition, chronic-stroke patients do not recover functionally after spontaneous recovery and are likely to experience non-use syndrome as a result of long-time non-use, even though they learn how to acquire motor skills with the affected arm[8, 10]. However, few studies have investigated how the major impairments of chronic-stroke patients are related to the recovery of upper extremity motor function.

This study investigated whether the degree of upper extremity motor function was discriminative in predicting the risk of hypertonia in chronic-stroke survivors who had experienced disability from stroke for more than 12 months, and analyzed the correlation between arm motor function and hypertonia to determine is predictive validity.

SUBJECTS AND METHODS

This was a descriptive cross-sectional study. A cohort of stroke patients from a rehabilitation center was recruited. The patients were recruited by advertising at the rehabilitation center. Forty-six chronic stroke patients were recruited and screened by research assistants using the following criteria. The participants were chronic stroke patients who were diagnosed with stroke for the first time >12 months previously, who: 1) scored 24 or more in the mini-mental state examination, 2) had no secondary deformation due to musculoskeletal disease in the upper extremities, 3) had no unadjusted diabetes mellitus, 4) were able to flex their affected wrist joint ≥10° and actively move 2 fingers[14], and 5) had no shoulder subluxation of a distance less than half of a fingerbreadth when the humeral head of the affected arm and subacromial space were palpated by the index finger without traction in a sitting posture[15, 16]. Because upper extremity pain might have affected the examination results, a discrimination test of the pain degree was conducted through external rotation and abduction of the shoulder joint by placing the palm on the back (hand-behind-neck test)[15, 17]. A research assistant instructed participants to express their degree of pain verbally based on a numerical rating scale when their affected arm was moved passively[18]. Pain of ≥5 on a visual analog scale in the hand-behind-neck test was considered the threshold value of probability and subjects reporting pain ≥5 were excluded from this study[17, 19]. Forty-three chronic stroke patients who fulfilled the criteria participated in the study. The baseline characteristics of our subjects are shown in Table 1. All the participants provided their signed informed consent after receiving an explanation of the purpose and procedure of the study.

The elbow flexor tone was assessed using the Modified Ashworth Scale (MAS). In most cases, a stroke patient's muscle tone is difficult to evaluate because abduction and external rotation of the shoulder joint decreases regardless of the presence of upper extremity muscle tone. Therefore, the elbow flexor tone was selected because spasticity of the elbow flexor is common in stroke patients[8, 15]. For the test, the forearm was placed in the supine position with the patients sitting comfortably. To determine the scope of movement of the forearm, the assessor instructed the participants to relax comfortably when the elbow joint was fully stretched. Even when moving slowly, the reflex action does not appear. Thus, this study used a dichotomous variable 0 for MAS ≤1; 1 for MAS $\geq 1^+$. Muscle tone increased significantly when the patients with MAS>1^+held an object and then released it compared with the patients with MAS of 0 or 1. This value has a high inter-rater reliability (weight κ=0.77–0.96) and intra-rater reliability (weight κ=0. 77–0.83)[20].

The motor recovery of the upper extremity was evaluated using the Fugl-Meyer (FM) assessment. The score for the upper extremity has a total possible score of 66, and the scores for the wrist and hand have a total possible scores of 24; their reported inter-rater (r=0.94) and intra-rater (r=0.99) reliabilities are also high[21].

The Action Research Arm Test (ARAT) was used to measure the limit of motor function in the affected arm. The inter-rater reliability of the test is r=0.99, and its test-retest reliability is r=0.98[22].

One assessor was instructed in the examination method to minimize tainted variables. To help the subjects understand each examination, they were given verbal instructions or demonstrations 2 times, after which their sessions began with 2 minutes rest time between each session.

SPSS 16.0 was used for the statistical analysis. Pearson's correlation coefficient was calculated to investigate the correlation between variables, and the receiver operating characteristic (ROC) curve was used to identify the cutoff values that could predict increased muscle tone (elbow flexor hypertonicity was MAS≥1^+) for all examination tools. Examination accuracy was measured by the area under the ROC curve (AUC) and classified as non-informative (AUC=0.5), low accuracy (0.5<AUC≤0.7), moderately accurate (0.7<AUC≤0.9), very accurate (0.9<AUC<1), and perfect (AUC=1)[20]. To predict the risk of hypertonia, logistic regression analysis was conducted. The χ^2 test was performed to investigate the relationship between intergroup FM-UE depending on the cutoff value, elbow flexor tone, and FM-wrist/hand, and ARAT. The independent t-test was used to compare scores between FM-wrist/hand and ARAT depending on the cutoff value of FM-UE and the effect size was analyzed using Cohen's *d*, the standardized difference between the means of the groups with lower motor function

Table 1. characteristics of the participants

Characteristics	Values
Gender (Male/Female)	23/20
Age (years)	57.88±7.92
Duration after stroke (months)	15.21±3.32
Affected side (Left/Right)	24/19
Subtype of stroke (Infarction/Hemorrhage)	29/14

The values are presented as mean ± SD or mode

(FM≤24 points) and the groups with higher motor function (FM>24 points). The effect is very high when d≥1.2, high when d >0.8, and moderate when d has a value between 0.6 and 0.8. The level of statistical significance was α=0.05.

RESULTS

The correlations between hypertonia and the arm motor function variables are shown in Table 2. MAS negatively correlated with FM-UE, FM-wrist/hand, and ARAT (r=−0.34 to −0.72, p<0.01); FM-UE positively correlated with FM-wrist/hand and ARAT (r=0.78 to 0.72, p<0.01); and FM-wrist/hand positively correlated with ARAT (r=0.62, p<0.01). The prediction of hypertonia (MAS≥1$^+$) is shown in Table 3. ROC curve analysis indicated the cutoff values for predicting hypertonia were 24 for FM-UE, 5.5 for FM-wrist/hand, and 15.50 for ARAT. Thus, it was likely that the reference point that was able to predict the risk factor for hypertonia was MAS≥1$^+$. The odds ratio of being MAS ≥1$^+$ for each outcome variable is shown in Table 4. FM-UE was most influential in elbow flexor spasticity (MAS≥1$^+$), and the probability that it would be higher than MAS≥1$^+$ was 0.764 times greater in the subjects with FM-UE cutoff values ≤24 than in the subjects with FM-UE cutoff values >24. The correlation between MAS and arm motor function according to the FM-UE cutoff value is shown in Table 5. The comparison of arm motor function according to the FM-UE cutoff value is shown in Table 6. The effect size was Cohen's d≥1.27, suggesting that the better the proximal part function, the better the distal part function.

Table 2. Correlations between hypertonia and arm motor function

Variables	Hypertonia (MAS≥1$^+$)[a]	FM-U/E[b]	FM-wrist/hand[c]
FM-UE	−0.72*		
FM-wrist/hand	−0.34*	0.78*	
ARAT[d]	−0.41*	0.72*	0.62*

*Significant, *p<0.05
[a]MAS: Modified Ashworth Scale; [b]FM-UE: Fugl Meyer-Upper Extremity; [c]FM-wrist/hand: Fugl-Meyer-wrist/hand; [d]ARAT: Action Research Arm Test

DISCUSSION

Severe upper motor neuron damage not only slows down motor recovery but also aggravates characteristics such as hyperexcitability[23)]. In stroke patients, increased muscle tone negatively correlates with motor function[24)]. In the present study, elbow flexor tone was found to negatively correlate with FM-UE (r=−0.72), FM-wrist/hand (r=−0.34), and ARAT (r=−0.41). In most stroke patients, the range of motion of abduction and external rotation in the shoulder decreases regardless of upper extremity muscle tone[8, 15)], and the gross movement patterns of shoulder flexion and internal rotation, forearm pronation, and elbow, wrist, and finger flexion make normal movement difficult[12)]. In particular, excessive elbow flexor tone reduces the stability and mobility of the wrist and makes fine finger movement difficult[5)].

Previous studies have demonstrated that poor motor function predicts the risk of hypertonia[8, 23)]. In the present study, the cutoff values for upper extremity motor function assessments that can predict hypertonia were identified as 24 for FM-UE, 5.5 for FM-wrist/hand, and 15.5 for ARAT. As a reference point that can predict the risk factors for hypertonia, the probability of MAS≥1$^+$ is high for elbow flexor spasticity, and the AUC were all at 76% or more, which was satisfactory. A previous study suggested that patients

Table 3. Prediction of hypertonia (MAS ≥1$^+$) in participants

Predictions	Criteria	Cut-off point	Sensitivity (%)	Specificity (%)	AUC[a] (95% CI)
FM-UE[c]	MAS[b]<1$^+$ vs MAS≥1$^+$	≤24/ 66 score	0.82	0.65	0.80** (0.68–0.93)
FM-wrist/hand[d]		≤5.5/ 24 score	0.83	0.73	0.86** (0.75–0.97)
ARAT[e]		≤15.50/ 57score	0.82	0.62	0.76* (0.61–0.90)

*Significant, *p<0.01, **p<0.001
[a]AUC: area under the ROC curve; [b]MAS: Modified Ashworth Scale; [c]FM-UE: Fugl Meyer-Upper Extremity; [d]FM-wrist/hand: Fugl Meyer-wrist/hand; [e]ARAT: Action Research Arm Test

Table 4. Odds ratios of being MAS ≥1$^+$ for each outcome variable

Predictions	Criteria	β	SE	Wald	odds ratio	p (95% CI)
FM-UE[b]	MAS[a]≤1 vs MAS≥1$^+$	−0.269	0.106	6.425	0.764	0.011* (0.62–0.94)
ARAT[c]		0.307	0.150	4.169	1.359	0.051 (1.01–1.82)
FM-wrist/hand[d]		−0.528	0.314	2.826	0.590	0.093 (0.32–1.09)

*Significant, *p<0.05
Dependent variable: 0 = MAS ≤1, 1 = MAS ≥1$^+$
Independent variable: sex, age, affected side, duration
[a]MAS: Modified Ashworth Scale; [b]FM-UE: Fugl Meyer-Upper Extremity (0=≤24 score, 1=>24 score); [c]ARAT: Action Research Arm Test (0=≤15.50 score, 1=>15.50 score); [d]FM-wrist/hand: Fugl Meyer-wrist/hand (0=≤5.5 score, 1=>5.5 score)

with FM-UE≤18 within 48 hours after stroke are 12.8 times more likely to experience hypertonicity (MAS ≥1+) within 6 months after onset than patients with FM-UE>18[6]. Using this cutoff value (FM-UE ≤18), a significant difference that could predict the risk of hypertonia was found in the present study. FM-UE ≤18 could distinguish patients with increased hypertonicity (MAS ≥1+) with 68% sensitivity, which is lower than the 82% sensitivity of FM-UE ≤24, and could distinguish patients without hypertonicity with 64% specificity, similar to the 65% specificity of FM-UE ≤24. Therefore, FM-UE ≤24 was used as the cutoff value to distinguish chronic-stroke patients with increased elbow joint flexor muscle tone, and these patients also had poor motor function of the upper extremity, because the gross movement patterns including internal rotation of the shoulder and flexion of wrist and finger appeared when holding or manipulating an object with their hands. Limited arm motor function in chronic-stroke patients can increase the risk of severe hypertonia, but various factors such as individual physical characteristics, specific treatment, and life habits can also influence muscle tone[5]. In addition, the subjects had experienced disability due to stroke for 15.21 months on average after onset, but the motor function of the upper extremity had improved through self-effort and treatment. Our FM-UE cutoff value was 6 points higher than that of a previous study indicating that spontaneous recovery can no longer be expected in patients with disability for 15 months after stroke onset; however, because the effect size of the intervention and spontaneous effort is high, their condition can be improved.

By examining the risk of hypertonia using the cutoff value of arm motor function in the present study, elbow joint flexor hypertonicity (MAS≥1+) was found to be most influenced by FM-UE, and when the FM-UE cutoff value was ≤24, it is likely to increase with a probability of 0.764 times (odds ratio) compared with subjects with FM-UE cutoff values >24. FM-wrist/hand and ARAT are largely used to examine the distal upper extremity and thus cannot be used to predict the risk of hypertonia. The subjects showed difficulty with hand functions such as manipulation, grip, pinch, and release; therefore, their FM-UE, FM-wrist/hand, and ARAT scores were lower. In FM-UE, the scores of the forearm, wrist, and hand (finger)-related items were not high, suggesting that the characteristics of the tool used to examine the distal upper extremity are most influential for elbow flexor tone. In the examination of upper extremity motor function, most subjects showed relatively high wrist joint and elbow flexor tone and, in particular, it is said that appropriately releasing an object is more difficult than gripping or holding an object[25]. For the upper extremity function, the fingers, hand, and wrist need to cooperate and selectively adjust. The muscle paralysis caused by central nervous system damage is more influential in distal than proximal parts and delays recovery[26]. FM-wrist/hand and ARAT showed significantly lower scores in predicting elbow flexor spasticity. Elbow flexor spasticity is a common phenomenon, and excessive elbow flexor tone prevents appropriated coordination of elbow extension, inhibiting the stability and movement of

Table 5. Correlation between MAS and arm motor function according to the cutoff value of FM-UE

Variables	FM-UE[a] cutoff value (>24 score) (n=23)	FM-UE cutoff value (≤24 score) (n=20)	χ^2
(MAS[b] ≤ 1)	13 (56.52%)	1 (5%)	12.932*
(MAS ≥ 1+)	10 (43.48%)	19 (95%)	
FM-wrist/hand[c] (≤5.5 score)	4 (17.39%)	18 (90%)	22.572*
FM-wrist/hand (>5.5 score)	19 (82.61%)	2 (10%)	
ARAT[d] (≤15.50 score)	1 (4.35%)	18 (90%)	31.823*
ARAT (>15.50 score)	22 (95.65%)	2 (10%)	

*Significant, *p<0.001
[a]FM-UE: Fugl Meyer-Upper Extremity; [b]MAS: Modified Ashworth Scale; [c]FM-wrist/hand: Fugl Meyer-wrist/hand; [d]ARAT: Action Research Arm Test

Table 6. Comparison of motor function according to the cutoff value of FM-UE

Variables	FM-UE[a] cutoff value (>24 score) (n=23)	FM-UE cutoff value (≤24 score) (n=20)	t	†Cohen *d*
FM-wrist/hand[b] (score)	11.13±6.74	2.80±2.02	5.314*	1.27
ARAT[c] (score)	35.70±14.28	7.50±6.13	8.186*	1.56

*Significant, * p<0.001
†Cohen *d* = size effect *d* = > 1.2 (very large), > 0.8 (large), 0.6 − 0.8 (moderate)
[a]FM-UE: Fugl Meyer-Upper Extremity; [b]FM-wrist/hand: Fugl Meyer-wrist/hand; [c]ARAT: Action Research Arm Test

the hand and wrist. When elbow joint flexor hypertonicity is present, sophisticated movement of the hand is impossible due to the lack of stability in the elbow joint. In addition, the rubrospinal tract is responsible for the arm stability, external support, and arm strength use to control the hand, and the corticospinal tract also plays a role in elbow flexion. Thus, it provides the basic background that enables sophisticated movements such as holding, gripping, and manipulating because it regulates the stability of the elbow and wrist and harmonious coordination with the extensors. Recovery after stroke is more rapid in the proximal than in the upper distal parts, seemingly because the elbow subluxation, impingement syndrome, supraspinatus tendinitis, and biceps tendinitis that commonly occur in stroke patients is influential in elbow flexor spasticity. Given that the coordination of elbow flexors and extensors in the movement of upper distal parts is an essential factor for forearm, wrist, and finger movements, it can be deduced that elbow flexor spasticity has a negative impact on upper extremity movement in stroke patients, and rotator cuff muscle and elbow extensor weakening form the upper extremity flexor pattern.

When muscle tone is MAS $\geq 1^{+}$, muscle resistance during passive stretch increases more than for MAS of 0 or 1, and the mechanical characteristics of the muscle change due to reflex hyperexcitability that may lead to contracture[5, 8]. Therefore, the elbow flexor is clinically useful for examining the muscle tone of the upper extremity[8]. An appropriate elbow flexor tone makes coordination with the elbow extensor possible, provides stability to the joint's distal parts, and allows appropriate wrist and finger movements[27]. Moreover, better motor function in the proximal parts of the upper extremity means there is less risk of increased muscle tone and better motor function in the distal parts of the upper extremity. Better stability in the proximal part of the shoulder (FM-UE>24) implies a lower elbow flexor tone and better distal part function of the upper extremity.

This study had a few limitations. The sample size was too small to generalize the results, and there were limitations in the definition of spasticity and determining whether elbow flexor hypertonicity reflects the typical characteristics of upper extremity muscle tone. However, given that coordination of the elbow flexors and extensors is an essential factor in forearm, wrist, and finger movement, it can be said that elbow flexor spasticity negatively influences the upper extremity movement of stroke patients. Therefore, further studies need to quantitatively investigate the impact of shoulder subluxation and pain degree on muscle tone and study the correlation between elbow flexor activity and amplitude and the muscle tone as well as analysis of upper extremity movement biomechanics.

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