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Relationship between Lower Extremity Muscle Mass, Leg Extension Strength and Muscle Power of Hemiplegic Stroke Patients

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Abstract. [Purpose] The purpose of this study was to examine the relationship between lower extremity muscle mass, leg extension strength and muscle power of hemiplegic stroke patients and to examine the differences in walking independence levels (dependent and independent groups) between each variable. [Subjects] The subjects were 21 hemiplegic patients at the first onset. [Methods] The affected and unaffected thigh muscle mass (TM), lower leg muscle mass, and lower extremity muscle mass (LEM) were measured by segmental bioelectrical impedance analysis. The leg extension peak torque (LEPT) and mean power (MP) were measured using a recumbent ergometer. Values obtained by dividing the affected and unaffected LEPTs by each LEM (LEPT/LEM) and the MP by total LEM (TLEM) of the affected and unaffected lower extremities (MP/TLEM) were calculated. [Results] The affected TM was significant lower than the unaffected side. The affected and unaffected TM was significantly correlated with the LEPT of each side. The affected TM, affected and unaffected LEPT, LEPT/LEM, MP and MP/TLEM of the dependent group were significantly lower than their respective values in the independent group. [Conclusion] These results suggest that a decrease in muscle mass in hemiplegic patients decreases anaerobic exercise capacity through weaker leg extension strength or muscle power.
Key words: Muscle power, Leg extension strength, Lower extremity muscle mass

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INTRODUCTION

The physical fitness components of stroke patients that are necessary for performing activities of daily living (ADL), including sitting up in bed and standing up to go to the bathroom, are the ability to perform activities within a certain period of time rather than the ability to perform an action for a long time, such as with systemic endurance. Power is the amount of work done within a unit of time, or the amount of energy expended, and it can be said to be a physical concept which is directly connected with ADL. Thus, the measurement of muscle power is an important element in the recording of the physical fitness level of stroke patients. However, previous studies on the physical fitness of stroke patients[1,2)] often focused on aerobic exercise capacity and we could find no report on the measurement of muscle power. Considering this, we developed a method to measure the lower extremity muscle power of hemiplegic stroke patients using a recumbent ergometer in a preceding study[3)], and confirmed its feasibility, reliability and validity. It is essential to know body composition since it is a factor that affects muscle power. Moreover, muscle mass is an important factor which affects muscle power, however, the relationships between them have not been thoroughly examined.

Evaluation methods with high reliability and validity, such as Magnetic Resonance Imaging (MRI)[4)] or Computerized Tomography (CT)[5,6)], have been used for the measurement of muscle mass in stroke patients. However, these evaluation methods are expensive measurement options without versatility or convenience. Recently, muscle mass measurement using Segmental Bioelectrical Impedance Analysis (S-BIA)[7)] which has high reliability and validity and a correlation coefficient of 0.9 or higher with MRI data, has been performed in clinical situations. Nevertheless, only a few studies have used S-BIA for muscle mass measurement in stroke patients[8,9)], and there are virtually no reports examining its relationship with muscle function, such as muscle strength or muscle power. In this context, the collection of basic data on muscle mass in stroke patients and examination of the relationship between these results and physical function or exercise capacity would be very useful for the rehabilitation of stroke patients.

This study examined the relationship between the measurement of muscle mass in hemiplegic stroke patients using S-BIA and the values of leg extension strength and muscle power obtained from recumbent ergometer pedaling measurements. Moreover, the differences in walking independence levels between muscle mass, leg extension strength and muscle power were also examined.

SUBJECTS AND METHODS

Subjects

The subjects of this study were in 21 hemiplegic stroke patients hospitalized in either of two hospitals: 18 males and 3 females whose mean age was 57.1 ± 9.6 years and mean body weight was 64.9 ± 13.1 kg. There were 9 patients with cerebral infarctions, 11 with cerebral hemorrhages and 1 with a subarachnoid hemorrhage. The characteristics of the subjects are shown in Table 1. Convalescing patients with a medically stable state who suffered hemiplegia at the first onset of cerebrovascular disease were included in this study and those with severe cardiorespiratory disease or lower extremity orthopedic disease were excluded. This study was performed with the approval of the Ethics Committee of Hirosaki University School of Medicine and only after obtaining the subjects' consents after giving each subject an explanation as to the purpose and details of this study.

Table 1. Characteristics of subjects

	All subjects (n=21)
Sex (Male / Female)	3/18
Age (years)	57.1 ± 9.6
Weight (kg)	64.9 ± 13.1
Period of onset (days) (Range)	65.6 ± 26.1 (23–140)
Disease Cerebral infarct	9
Cerebral hemorrhage	11
Subarachnoid hemorrhage	1
Side of hemiparesis (Right/Left)	11/10
L/E BRS 3	4
4	11
5	4
6	2
FIM total score	103.9 ± 14.3
Walking independence level (Independent/Dependent)	6/15

Mean ± standard deviation (SD), L/E; Lower Extremity, BRS; Brunnstrom Recovery Stage, FIM; Functional Independence Measure.

Methods

The age, sex, diagnosis, affected side and time since onset were identified from patients' medical records. Concerning the status of their physical functioning, subjects' lower extremity Brunnstrom Recovery stage (BRS) was confirmed, as well as their Functional Independence Measure (FIM). Furthermore, based on their FIM walking ability classification, 6 patients with scores of 6 or 7 were classified as the independent group and 15 patients with a score of 5 were classified as the dependent group.

An S-BIA body composition analyzer, Physion MD (Physion, Kyoto, Japan), was used for muscle mass measurement. For the measurement, subjects extended both the upper and lower extremities in a supine position on a bed with their arm and legs spread some 30 degrees apart from the trunk. So as to eliminate any body fluid balance variability, the patients stayed on the bed for 5 minutes. After cleaning the application sites with alcohol, electrodes were placed at 12 sites according to the maker's manual on the right and left sides: 1, the dorsal base between the index finger and middle finger; 2, the center of the wrist; 3, the elbow radial point; 4, the dorsal base of the second and third toes; 5, the centers of medial malleolus and lateral malleolus; and 6, the knee lateral to the tibia. Measurements were taken using two different induction methods (distal induction for the first measurement and proximal induction for the second) to obtain section impedance measurements. With the distal induction method, electric current was applied to the right and left sides at 1and 4. Voltage-sensing electrodes took measurements on the right and left sides at 2and 5. The electric current applied for the second measurement was the same as that for the first and the voltage-sensing electrodes took measurements at the right and left sides at 3and 6. As stated above, the first measurement was performed for the right and left upper extremities and lower extremities and the second was for the right and left upper arms and thighs; values for the right and left forearms and lower legs can be obtained by subtracting the second measurements from the first. In order to take measurements with subjects in a stable condition, patients were not measured in the following circumstances: immediately after exercise, immediately after having a bath, within 2 hours after eating or having a large fluid intake, 30 minutes after awakening, before defecation or urination, after assuming a prolonged standing posture, having a fever, within 30 minutes after entering a room from an ambience with a temperature difference of 10 degrees or more, when there was high deformation of the extremities, or when there was any *in vivo* metal implant. Moreover, when any metal product or magnetic product directly made contact with a patient's skin, they were removed before measurement to prevent in accurate measurement. This study used the affected and unaffected thigh muscle mass, lower leg muscle mass, and lower extremity muscle mass (the total muscle mass of the thighs and lower legs) as indicators.

The StrengthErgo240 (SE240, Mitsubishi Electric Engineering Company, Ltd., Tokyo, Japan) recumbent ergometer was employed to measure leg extension strength and lower extremity muscle power. In the pedaling position, each subject grasped the arms equipped on the right and left sides of the seat to support the upper extremities; the angle of the backrest was set at 110 degrees relative to the seat face, and their trunk was secured with a safety-belt. The position of the seat was set so that knee flexion was 30 degrees when the lower extremity was in the maximum extended position. A cycle with a crank length of 170 mm was used and a crank with an external rotation preventing

Table 2. Result of each measurement (muscle mass, lower extremity peak torque, mean power) and comparison of unaffected side and affected side of hemiplegic stroke patients

	Unaffected side	Affected side
Muscle mass (kg)		
Thigh	3.39 ± 0.68	3.22 ± 0.75**
Lower leg	1.48 ± 0.31	1.48 ± 0.29**
Lower extremity	4.88 ± 0.94	4.70 ± 0.99**
LEPT (Nm)	85.55 ± 39.88	48.31 ± 35.13**
LEPT/LEM (Nm/kg)	17.53 ± 7.11	10.07 ± 6.56**
MP (W)	217.59 ± 165.77	
MP/TLEM (W/kg)	22.19 ± 15.08	

Mean ± standard deviation (SD), **; $p<0.01$ by paired t-test. LEPT; Lower extremity Extension Peak Torque, LEM; Lower Extremity Muscle mass, MP; Mean Power, TLEM; Total Lower Extremity Muscle mass.

mechanism was used for subjects with a risk of riding instability, which may be caused by external rotation due to inadequate control of the hip joint.

For leg extension strength measurement, Lower extremity Extension Peak Torque (LEPT) was determined from 5 rotational pedaling motions at the rate of 50 rotations/minute in an isokinetic mode. The measurement was performed twice and the LEPTs of the affected lower extremity and unaffected lower extremity were calculated. Furthermore, the values obtained by dividing the affected and unaffected LEPTs by each Lower Extremity Muscle mass (LEM) (LEPT/LEM: Nm/kg) were also calculated.

For the lower extremity muscle power measurement, a modified-Wingate Anaerobic Test (m-WAnT) for hemiplegic stroke patients was performed with reference to a preceding study[10]. The load used for the m-WAnT was calculated with the following formula using the affected and unaffected LEPTs obtained in the leg extension strength measurement.

Load = 0.273 × (Unaffected LEPT) + 0.151 × (Affected LEPT) – 7.97 (constant)

All-out pedaling motion was performed with the load ramped from 0 to 6 seconds after the start of exercise and held at a constant load from 6 to 9 seconds in order to calculate the Mean Power (MP). A 3-minute warm-up and cool-down were performed with a load of 10 W before and after the test. In addition, as in the case of the leg extension strength, the MP was divided by the Total Lower Extremity Muscle mass (TLEM) of the affected and unaffected lower extremities (MP/TLEM: W/kg).

The paired t-test was performed for calculating the difference in the muscle mass of each site between the affected and unaffected sides (thigh, lower leg, and lower extremity) and the difference in LEPT and LEPT/LEM between the affected and unaffected sides. Spearman's rank correlation coefficient was used to examine the relationships between each variable, including the affected and unaffected thigh muscle mass, lower leg muscle mass, lower extremity muscle mass, LEPT, LEPT/LEM, MP, MP/TLEM as well as the lower extremity BRS. In order to investigate the difference in the walking independence level between the muscle mass, LEPT, LEPT/LEM, MP, and MP/TLEM at each site, the non-paired t-test was performed for each group.

SPSS 16.0 software was used for statistical processing and differences were considered significant at values of $p<0.05$.

RESULTS

The results of the measurement of muscle mass, leg extension strength, and muscle power are shown in Table 2.

Regarding the difference in muscle mass between the affected and unaffected sides, thigh muscle mass and lower extremity muscle mass were significantly lower on the affected side ($p<0.01$). There was no significant difference in lower leg muscle mass. As for the differences in LEPT and LEPT/LEM between the affected and unaffected sides, both variables were significantly lower on the affected side ($p<0.01$).

The relationships between muscle mass, LEPT, MP, and lower extremity BRS at each site are shown in Table 3. Regarding the relationship between muscle mass and LEPT at each site, though there were significant correlations between the affected LEPT and thigh muscle mass ($rs = 0.472$, $p<0.05$), between the affected LEPT and lower extremity muscle mass ($rs = 0.486$, $p<0.05$) and between the unaffected LEPT and thigh muscle mass ($rs = 0.473$, $p<0.05$), no significant correlation was observed between the bilateral lower leg muscle mass and the unaffected lower extremity muscle mass. As for the relationship between the muscle mass and MP at each site, though there were significant correlations with the affected thigh muscle mass ($rs = 0.477$, $p<0.05$), lower extremity muscle mass ($rs = 0.462$, $p<0.05$), unaffected thigh muscle mass ($rs = 0.519$, $p<0.05$) and lower extremity muscle mass ($rs = 0.435$, $p<0.05$), there was no correlation with the bilateral lower leg muscle mass. There was no correlation between the muscle mass and the lower extremity BRS. The relationships between the lower extremity BRS and LEPT, LEPT/LEM, MP, and MP/TLEM are shown in Table 4. There were very significant correlation between the lower extremity BRS

Table 3. Correlation coefficients between muscle mass and LEPT, MP and BRS

Variable	Muscle mass					
	Unaffected side			Affected side		
	TM	LLM	LEM	TM	LLM	LEM
Unaffected LEPT	0.473*	0.225	0.372	–	–	–
Affected LEPT	–	–	–	0.472*	0.399	0.486*
MP	0.519*	0.281	0.435*	0.477*	0.25	0.462*
BRS	–0.167	–0.239	–0.255	–0.132	–0.256	–0.18

*; p<0.05, **; p<0.01, by Spearman's rank correlation coefficients. LEPT; Lower extremity Extension Peak Torque, MP; Mean Power, BRS; Brunnstrom Recovery Stage, TM; Thigh Muscle mass, LLM; Lower Leg Muscle mass, LEM; Lower Extremity Muscle mass.

Table 4. Correlation coefficients between BRS and LEPT, LEPT/LEM, MP and MP/TLEM

	Unaffected side		Affected side			
Variable	LEPT	LEPT/LEM	LEPT	LEPT/LEM	MP	MP/TLEM
BRS	0.154	0.261	0.594**	0.736**	0.271	0.428

**; p<0.01, by Spearman's rank correlation coefficients. BRS; Brunnstrom Recovery Stage, LEPT; Lower extremity Extension Peak Torque, LEM; Lower Extremity Muscle mass, MP; Mean Power, TLEM; Total Lower Extremity Muscle mass.

Table 5. Comparison of each measured value with walking independence level (independent and dependent group)

Variable	Independent group (n=6)	Dependent group (n=15)
Muscle mass		
Unaffected side		
TM (kg)	3.84 ± 0.80	3.22 ± 0.56*
LLM (kg)	1.58 ± 1.44	1.44 ± 0.29
LEM (kg)	5.42 ± 1.15	4.66 ± 0.79
Affected side		
TM (kg)	3.75 ± 0.92	3.01 ± 0.58†
LLM (kg)	1.54 ± 0.26	1.46 ± 0.30
LEM (kg)	5.29 ± 1.17	4.47 ± 0.83
LEPT (Nm)		
Unaffected side	128.03 ± 29.29	68.55 ± 29.71**
Affected side	93.95 ± 25.80	30.05 ± 16.59**
LEPT/LEM (Nm/kg)		
Unaffected side	23.62 ± 2.69	15.09 ± 6.88**
Affected side	18.10 ± 4.71	6.86 ± 3.86**
MP (W)	421.32 ± 137.35	136.10 ± 87.26**
MP/TLEM (W/kg)	39.80 ± 11.00	15.15 ± 9.78**

Mean ± standard deviation (SD), *; p<0.05, **; p<0.01, †; p=0.057 by non-paired t-test. TM; Thigh Muscle mass, LLM; Lower Leg Muscle mass, LEM; Lower Extremity Muscle mass, LEPT; Lower extremity Extension Peak Torque, MP; Mean Power.

and affected LEPT (rs = 0.594, p<0.01) and between the lower extremity BRS and affected LEPT/LEM (rs = 0.736, p<0.01) (Table 4).

The differences in the walking independence level are shown in Table 5. With reference to muscle mass, the results showed that there was a significantly lower value of affected thigh muscle mass in the dependent group compared to the independent group (p<0.05) and the dependent group showed a tendency to have a lower value in the unaffected thigh (p = 0.057) . There were no significant differences at the other sites. The differences in the affected and unaffected LEPT and LEPT/LEM and MP and MP/TLEM between the independent group and the dependent group were very significantly lower in the dependent group than in the independent group (p<0.01 for both).

DISCUSSION

This study partially measured the lower extremity muscle mass of hemiplegic stroke patients using S-BIA and examined the differences in the thigh, lower leg, and lower extremity muscle mass between the affected and unaffected sides. Furthermore, the relationships between obtained muscle mass and the affected and unaffected leg extension strength and muscle power obtained with a recumbent ergometer were examined.

Muscle mass measurement in stroke patients in the past has been performed using methods with high reliability and validity, such as CT or MRI. Metoki et al.[11] measured the thigh muscle mass of hemiplegic stroke patients using CT, and showed that there was a significantly lower value in the affected muscle mass. Odajima et al.[12] compared lower extremity muscle mass between hemiplegic patients and healthy adults using CT, and reported that the muscle cross-sectional areas of unaffected quadriceps femoris, thigh adductors, lower leg extensors, and lower leg flexors are significantly lower in hemiplegic patients than in healthy adults. In a study using S-BIA equipment, which was also used in this study, Yamashita et al.[8] compared the difference between the unaffected and affected sides of hemiplegic stroke patients and the difference in healthy adults between the right and left sides, and reported that stroke patients showed a significantly bigger difference in muscle mass of both the upper and lower extremities. The present study also showed that there was a significantly lower value of lower extremity muscle mass on the affected side compare to the than on unaffected side. The present study partially compared thigh muscle mass and lower leg muscle mass, and showed that values for the thigh were significantly lower on the affected side; however, there was no difference in lower leg muscle mass. The BIA method utilizes the fact that there is a difference in the ease with which an extremely weak current pass through tissues with a high moisture content, such as blood, cerebrospinal fluid and muscle, and those with a low moisture content, such as fat and bones, and uses this difference to estimate body composition[13,14]. For this reason, measurement errors may arise due to the moisture content of tissues. Most of the subjects in this study used a wheelchair to move around during their daily life and we assumed that they would easily develop edema in the lower legs due to being in a sitting position for long periods of time. Moreover, muscle activity is extremely limited in the affected lower leg due to the influence of motor palsy as well, resulting in a limited muscle pumping action. As a result, such patients often develop edema owing to disrupted fluid circulation in the affected lower leg and under such circumstances the measurement results would give results higher than they really were. Consequently, there may have been no statistical difference in muscle mass between the affected and unaffected sides.

Regarding the relationship between the lower extremity muscle mass and leg extension strength, Nakao et al.[15] reported that there was a positive correlation between the isometric knee extension muscle strength and thigh muscle mass obtained with the S-BIA method in a study performed on with community-dwelling elderly females as subjects. The present study demonstrated a positive correlation between the affected and unaffected leg extension strength obtained in an isokinetic pedaling motion and thigh muscle mass. While the lower muscle group to be used varies between knee extension strength as a monarticular movement and leg extension strength as a compound joint movement, the results suggest that thigh muscle mass is important for exerting muscle force in regards to both strengths. Furthermore, the present study also examined leg extension strength divided by the affected and unaffected lower extremity muscle mass. This revealed that the mean affected LEPT/LEM was 10.1 Nm/kg and the mean unaffected LEPT/LEM was 17.5 Nm/kg, showing a statistically significant lower value for the affected lower extremity. This result shows that the degree of muscle strength because per unit muscle mass was low in the affected lower extremity, presumably the physiological function of the affected motor unit was weakened[16]. Furthermore, because there was a correlation between the lower extremity BRS and the affected LEPT/LEM, if paralysis were severe, the degree of muscle strength exerted per unit muscle mass could be considered to be lower.

Concerning the relationship between the lower extremity muscle mass and muscle power, Chia[17] stated that a study performed using boys and girls at the ages of 13 to 14 as subjects, showed a correlation between the lower extremity muscle weight measured by dual energy X-ray absorptiometry, Peak Power obtained by performing the Wingate Anaerobic Test, and MP. The present study showed a significant correlation between the muscle power and bilateral thigh muscle mass and between muscle power and lower extremity muscle mass, suggesting that muscle mass is one of the important factors for exerting muscle power, even in hemiplegic stroke patients. However, since it was the muscle power obtained from a pedaling motion, the involvement of lower leg muscle mass cannot be denied. Therefore, it is necessary to review the lower leg muscle mass measurement or calculation methods.

Leg extension strength and muscle power measurements performed during the present study were part of an exercise that requires brief maximal effort. Hence, it is essential for the exercised muscles to make type 2 fibers, which are responsible for anaerobic exercise capacity, to act advantageously. Hachisuka et al.[18] quantitatively evaluated affected and unaffected lower extremity muscle tissue and additionally examined the enzyme tissue biochemical findings, length of time from stroke onset, the degree of paralysis or ADL, activity of daily life, etc. Their results showed that there was type 2A fiber- or type 2B fiber-dominant muscle atrophy on the affected side and type 2B fiber-dominant muscle atrophy on the unaffected side of hemiplegic patients, which was unrelated to the severity of the stroke or ADL level, but was correlated with the decrease in daily physical activity. In addition, they stated that the degree of muscle atrophy was higher on the affected side than on the unaffected side.

This study compared muscle mass, leg extension strength, and muscle power with walking independence. There was a tendency for thigh muscle mass to be lower on the affected side and unaffected side in the dependent group but there was no correlation between the muscle mass and lower extremity BRS. This result indicates, as shown in the report by Hachisuka et al.[18], that muscle mass was low on both the affected and unaffected sides in the dependent group, which was also considered to have low daily physical activity. Furthermore, Landin et al.[19] reported that there was no muscle fiber atrophy of either type in the affected vastus lateralis of ambulatory hemiplegic patients but that there was an increase in the ratio of type 2 fibers, suggesting that daily physical activity is very closely related to muscle atrophy. Moreover, the present study showed a significantly lower value of leg extension strength and muscle power in the dependent group than in the independent group. One possible reason for the fact that the leg extension strength and muscle power, which were anaerobic exercise capacities, were not adequately exerted is that muscle atrophy following the development of a stroke was type 2 fiber-dominant.

Based on the above, we suggest that the decrease in muscle mass in the hemiplegic stroke patients mainly reflected atrophy of type 2 fibers, which led to the observed decrease in anaerobic exercise capacity, as measured by leg extension strength or muscle power. It is also important to measure the anaerobic exercise capacity, through as muscle mass, muscle strength, or muscle power, as well as measuring systemic endurance, or aerobic exercise capacity, as part of a physical fitness evaluation. Accordingly, we believe the result of this study is of clinical significance in the comprehensive understanding of the physical fitness of stroke patients. Furthermore, it is important to prevent and improve muscle atrophy at an early stage during rehabilitation after stroke, and performing muscle strength or muscle power-focused therapeutic exercise may lead to early walking independence. Following on from the results of this study, we aim to elucidate the physical fitness of stroke patients through a longitudinal examination of changes in muscle mass, muscle strength, and muscle power and a comparison with their exercise capacity or ADL.

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