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TRUNK MUSCLES IN PERSONS WITH HEMIPARETIC STROKE EVALUATED WITH COMPUTED TOMOGRAPHY

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Objectives: **To analyse side difference in bilateral trunk muscles in patients with hemiparetic stroke, to relate it with impairment and disability variables and to evaluate longitudinal changes.**

Methods: **In a sample of 83 inpatients with hemiparetic stroke undergoing rehabilitation, we measured the cross-sectional area of the paravertebral muscle and thigh muscles using computed tomography at admission and discharge. Classifying them by paravertebral muscle side difference (group I: contralateral > ipsilateral; II: contralateral = ipsilateral; III: contralateral < ipsilateral) we analysed group difference in the Stroke Impairment Assessment Set, the Functional Independence Measure and walk velocity.**

Results: **In contrast to thigh muscles, the paravertebral muscle cross-sectional area was significantly greater on the side contralateral to the brain lesion. Discharge paravertebral muscle cross-sectional area increased significantly from admission values. The Stroke Impairment Assessment Set, Functional Independence Measure and walk velocity were significantly lower in group I.**

Conclusion: **The contralateral paravertebral muscle cross-sectional area was larger than the ipsilateral ones, and this was related to the degree of impairment and functional limitations.**

Key words: cerebrovascular disorders, rehabilitation, exercise, outcome assessment.

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INTRODUCTION

Trunk muscles play an important role in the support of our bodies in antigravity postures such as sitting and standing and in the stabilization of proximal body parts during voluntary limb movements (1, 2). Our clinical experience suggests that their function is essential in successful rehabilitation of patients with stroke, especially in the acquisition of basic activities and activities of daily living (ADL). In fact, Franchignoni et al. (3) indicated the importance of assessing trunk function in order to predict patients' functional status at discharge. Although there are many studies regarding affected side limb functions and their recovery, information is limited about trunk muscles. This may partly be due to their limited accessibility to direct clinical examination and to the greater contribution from uncrossed cortical fibres compared with limb muscles.

Previous investigators have studied trunk muscles in stroke patients with clinical scales (4–6), muscle strength measurements (7, 8), electrophysiological means (surface electromyography (9) or transcortical magnetic stimulation (10, 11)) and morphological measures (computed tomography (CT) scan (12) or magnetic resonance imaging (MRI) (13)).

Several instruments designed to describe stroke impairment contain items to assess trunk function as a part of the assessment. In the Stroke Impairment Assessment Set (SIAS) (14, 15) it is assessed with the verticality test and the abdominal muscle strength test and in the Fugl-Meyer method (16) it is evaluated as the sitting ability and the parachute reaction. The trunk control test (TCT) (5), which assesses the ability to roll over, sit up and maintain sitting, was proposed as a standardized measure to assess trunk function, and was successfully used to predict functional outcome of stroke (3). Although these scales are useful for clinical assessment, it is difficult to interpret reasons for changes in scores, because improvement can be brought about not only by improved trunk control but also by other factors such as a recovery in disturbed consciousness, hemineglect or ataxia.

Using a hand-held dynamometer, Bohannon (7) reported that lateral trunk flexion strength was significantly decreased on the affected side compared with the unaffected side, while Tanaka et al. (8) found no significant difference between the sides in trunk rotation strength, as measured with an isokinetic dynamometer. These results should be interpreted with caution, because it is difficult to isolate unilateral trunk strength or to exclude simultaneous limb movements completely.

In healthy persons, recent electrophysiological studies using transcortical magnetic stimulation revealed that cortical pathways to trunk muscles were represented bilaterally in the cortical hemispheres, although contralateral pathways were considered dominant (10, 11). Fujiwara et al. (17) found significantly more frequent recording of ipsilateral paravertebral muscle motor

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evoked potential (MEP) in patients with hemiparetic stroke compared with healthy persons and suggested that compensatory activation of uncrossed pathways (18) may play a role in the recovery of trunk function.

Morphological studies with CT or MRI can directly visualize trunk muscles. Using CT, Suzuki et al. (12) found no significant differences in paravertebral muscle cross-sectional areas (CSA) between the 2 sides ipsilateral and contralateral to the brain lesion in 80 patients with hemiparetic stroke. On the contrary, Tanaka et al. (13) found ipsilateral paravertebral muscle hypertrophy as assessed with MRI, and suggested that it was related to increased paravertebral muscle activities as recorded with a Holter electromyography. Thus the question remains unanswered whether side difference really exists in paravertebral muscle of persons with hemiparetic stroke. It is also unknown how the paravertebral muscle size is related to the severity of hemispheric lesion as inferred from the degree of limb paresis and functional limitation, or how it changes longitudinally during the course of a rehabilitation program. To answer these questions, we measured CT parameters of bilateral paravertebral muscle both at admission and discharge, and related them to demographic, impairment and disability variables. As a comparison, the CT parameters were measured for thigh muscles whose innervation is considered predominantly unilateral.

METHODS

The initial sample comprised 131 consecutive patients with recent onset, first-time hemispheric stroke who had been admitted from June 1996 to December 1997 to a tertiary rehabilitation hospital with 120 beds located in the Tokyo metropolitan area in Japan. Stroke was diagnosed either with CT scanning or MRI. We excluded patients who could not follow commands (16 patients), who had severe ischaemic heart disease (1 patient) or uncontrolled hypertension (1 patient) or who had no motor involvement (13 patients). After excluding them, the final sample comprised 100 patients (67 males) with an average age at admission of 53.5 (SD 10.0, range 24–76) years. There were 37 with cerebral infarction, 54 with cerebral haemorrhage and 9 with cerebral infarction secondary to subarachnoid haemorrhage. Fifty-four patients had right-sided brain lesion and the remaining 46 had left-sided lesion. Forty-four patients had a cortical lesion and the other 56 patients had a subcortical lesion. The median days from stroke onset to admission and the median length of hospital stay were 87.5 (11–280) and 104.5 (45–177) days, respectively. Before enrolment, the purposes and procedures were fully explained to the patients and their caregivers, and a written informed consent was obtained. Five times a week, the subjects underwent a conventional stroke rehabilitation program consisting of range of motion (ROM) exercises, muscle strengthening, basic activity training, gait and activities of daily living (ADL) training, and speech therapy or cognitive retraining as indicated. We evaluated the following parameters at the start (within 2 weeks from admission) and at the end (within 2 weeks before discharge) of a rehabilitation program.

Patient characteristics

As an index of body dimension, we calculated the body mass index (BMI = body weight (kg)/(height (m))^2). We assessed the degree of limb paresis with the motor items of the SIAS, which is a standardized measure of stroke impairments consisting of the motor, tone, sensory, range of motion, pain, trunk function, visuospatial function, speech and unaffected side function (14, 15). The interrater reliability, unidimensionality, and concurrent as well as predictive validity of the SIAS have already been reported (14, 15, 19). The proximal and distal motor functions of the affected limbs, assessed with the knee-mouth, finger function, hip-flexion, knee-extension and foot-pat items of the SIAS, were rated from 0 to 5, where 0 means complete paralysis, 3 the ability to complete the task with clumsiness, 5 no paresis and 2 and 4 in between. Three trained physiatrists (physicians who are specialists in the field of physical medicine and rehabilitation) in charge of the patients assessed the SIAS.

The degree of functional limitation was assessed with the Functional Independence Measure (FIM) (20), a standardized instrument of disability with well-established scale quality (21). It was scored by trained physiatrists, nurses or therapists in charge of the patients. In 62 patients who were ambulatory, the walk velocity to cover a distance of 20 metres, which is reported to correlate with the degree of gait disturbance (22), was measured at their most comfortable speed with canes and/or orthosis allowed when necessary.

Quantitative muscle computer tomography

The examination was performed with a Vertex 3000$^{\text{TM}}$ CT scanner (GE Yokogawa Medical systems Co. Ltd, Tokyo, Japan) under the conditions of an X-ray of 120 kVp, 300 mA, a scanning time of 1.0 seconds and a slice thickness of 5 mm (23). The scanning site was at a midpoint of the third lumbar vertebral body. Using the scanner computer system we measured the CSA and mean CT number of the paravertebral muscles as a whole, because this is more easily and accurately accomplished than measuring individual muscles. The CSAs and CT numbers of bilateral thigh muscles were also measured at the mid-thigh level as a comparison with paravertebral muscles. We measured the CSA and CT number of the thigh muscles as a whole, which are known to correlate well with those of quadriceps muscles as previously reported by our group (24). The muscle CSA measured in this study represented the area having the CT numbers of normal muscle that range from 30 to 120 Hounsfield units (HU) as previously described by Liu et al. (23). To ensure stability of the measured CT numbers, we performed weekly water calibration in addition to annual full quality control procedures as described by McCullough (25). Throughout the study, the CT number of water phantom remained within ±2 HU, indicating satisfactory stability. The coefficients of variation of ten repeated measurements of the same sample were 4% for CT numbers and 3% for muscle CSA.

Data analysis

The differences in paravertebral muscle CSA and CT numbers between the two sides ipsilateral and contralateral to the brain lesion at admission and at discharge were analysed with a 2-way ANOVA, with *side* (ipsilateral and contralateral) and *time* (admission and discharge) as the main factors. To classify the patients into 3 groups based on the degree of the difference in CSA between the two sides (group I: contralateral > ipsilateral CSA; group II: contralateral = ipsilateral CSA; group III: contralateral < ipsilateral CSA), we used ±5% side difference in CSA as a cut-off value, because the coefficient of variation of repeated measurements was 3% as described above. Accordingly, the patients were classified as group I: contralateral/ipsilateral CSA (d) > 1.05; group II: $1.05 > d > 0.95$; group III: $d < 0.95$. The differences in demographics (age, duration from stroke onset to the start and end of a rehabilitation program), body dimension (BMI), impairment (the SIAS motor score) and disability variables (the FIM score and walk velocity) were analysed using a two-way ANOVA, with the main factors being *group* (the 3 groups) and *time* (admission and discharge). Conditional on a significant F-value, *post hoc* tests were performed. Values were considered significant if $p < 0.05$ after making a Fisher's PLSD correction for multiple comparisons (26). The above analyses were performed with SPSS 11.0J$^{\text{TM}}$ software (SPSS Japan Inc., Tokyo, Japan).

RESULTS

Complete data set was obtained in 100 patients (100%) at admission and 83 patients (83%) at discharge. The reasons for dropouts were discharge earlier than planned (8 patients), which caused difficulty in scheduling for the second measurement, refusal (3 patients) and unstable medical conditions (6 patients). We performed statistical analyses about 83 patients with full

Table I. *Comparison of the cross-sectional areas (CSA) and computed tomography (CT) numbers between the two sides ipsilateral and contralateral to the brain lesion for paravertebral and thigh muscles (mean ± SD)*

	C	I	C/I (%)
Paravertebral muscles			
CSA (cm^2)			
Admission ($n = 83$)	17.4 (4.5)*,**	16.8 (4.2)	101.4 (18.4)
Discharge ($n = 83$)	18.2 (4.4)	17.3 (4.0)***	106.0 (10.7)
Discharge/admission (%)	104.8 (10.4)	103.6 (15.2)	–
CT number (HU)			
Admission ($n = 83$)	35.5 (6.1)*,**	34.8 (6.1)	102.5 (9.9)
Discharge ($n = 83$)	36.3 (5.7)	35.7 (5.8)***	102.1 (8.1)
Discharge/admission (%)	103.3 (11.4)	103.6 (11.8)	–
Thigh muscles			
CSA (cm^2)			
Admission ($n = 83$)	74.2 (25.1)*,**	94.3 (25.8)	78.6 (16.7)
Discharge ($n = 83$)	82.1 (25.5)	106.3 (25.4)***	77.0 (16.5)
Discharge/admission (%)	115.6 (36.5)	115.9 (26.5)	–
CT number (HU)			
Admission ($n = 83$)	41.8 (6.1)*,**	45.2 (5.2)	92.4 (7.9)
Discharge ($n = 83$)	42.3 (6.0)	45.7 (5.5)***	90.8 (7.8)
Discharge/admission (%)	102.0 (13.1)	101.6 (10.7)	–

C = contralateral side to the brain lesion; I = ipsilateral side to the brain lesion; HU = Hounsfield Unit.
* $p < 0.001$ versus discharge (contralateral); ** $p < 0.001$ versus admission (ipsilateral); *** $p < 0.001$ versus admission (ipsilateral).

data at discharge. There were no significant differences in the demographic, impairment and disability characteristics between patients with and without full data at discharge.

Table I demonstrates the paravertebral and thigh muscle CSA and CT number at admission and discharge. A two-way ANOVA with *side* and *time* as main factors showed a main effect of *time* [F (1, 82) = 11.1; $p < 0.01$ in the paravertebral muscle CSA, F (1, 82) = 5.4; $p < 0.05$ in the paravertebral muscle CT number, F (1, 82) = 39.0; $p < 0.01$ in the thigh muscle CSA, F (1, 82) = 3.9; $p < 0.05$ in the thigh muscle CT number], whilst a main effect of *side* [F (1, 82) = 23.7; $p < 0.01$ in the paravertebral muscle CSA, F (1, 82) = 6.4; $p < 0.05$ in the paravertebral muscle CT number, F (1, 82) = 194.0; $p < 0.01$ in the thigh muscle CSA, F (1, 82) = 107.9; $p < 0.01$ in the thigh muscle CT number]. There was no significant *time* × *side* interaction in the paravertebral and thigh muscle CSA and CT, indicating the effect of rehabilitation was the same for both sides. *Post hoc* tests showed that there were significant differences in the paravertebral and thigh muscle CSA and CT number at admission and discharge between the 2 sides. The CSA and CT numbers of paravertebral muscle contralateral to the brain lesion were significantly larger than the ipsilateral ones, while they were larger on the ipsilateral side for thigh muscles.

Table II represents the demographic, impairment and disability characteristics of the 3 groups defined by the degree of the size difference of the paravertebral muscle CSA. A two-way ANOVA with *group* and *time* as main factors showed a main effect of *time* [F (1, 80) = 51.4; $p < 0.01$ in the SIAS affected side motor score, F (1, 80) = 92.6; $p < 0.01$ in the walk velocity,

Table II. *Comparison of patient characteristics among the 3 groups defined by the degree of difference between the ipsilateral and contralateral paravertebral muscle cross-sectional areas (CSA) (mean ± SD)*

	Group I		Group II		Group III	
	($n = 34$) Admission	($n = 34$) Discharge	($n = 34$) Admission	($n = 34$) Discharge	($n = 15$) Admission	($n = 15$) Discharge
Contralateral/ ipsilateral CSA	1.1 (0.08)	1.1 (0.06)	1.0 (0.03)	1.0 (0.04)	0.9 (0.04)	0.9 (0.2)
Age (years)	53.6 (10.8)	–	50.8 (9.0)	–	52.4 (9.9)	–
From onset to admission (days)	100.9 (58.9)	–	101.2 (46.1)	–	104.9 (83.8)	–
Body mass index (BMI) (kg/m^2)	21.9 (3.2)	22.0 (2.5)	22.2 (2.8)	22.3 (2.4)	23.3 (1.7)	23.7 (2.6)
Affected side SIAS motor score	8.1 (4.6)^{a}	11.1 (3.2)	10.1 (5.3)	12.1 (5.3)	11.9 (7.6)^{a}	12.7 (1.7)
Walk velocity (m/s)	13.0 (4.5)^{a}	37.0 (3.6)^{b}	22.2 (5.4)^{c}	44.2 (5.0)	24.9 (6.3)^{ac}	52.7 (6.5)^{b}
FIM motor score	56.6 (11.4)^{ab}	75.1 (9.7)^{cd}	65.1 (11.8)^{b}	78.1 (8.3)^{c}	65.5 (8.3)^{a}	77.4 (7.8)^{d}
FIM cognitive Score	27.5 (6.7)	30.0 (5.3)	25.4 (7.5)	28.8 (5.3)	23.7 (6.6)	28.1 (4.8)

We classified the patients into 3 groups based on the degree of the difference in CSAs between 2 sides, group I: contralateral/ipsilateral CSA (d) > 1.05, group II: 1.05 > d > 0.95, group III: d < 0.95). ^{a,b,c,d} Statistically significant ($p < 0.01$).
FIM = functional independence measure; SIAS = Stroke Impairment Assessment Set.
Group I: contralateral >ipsilateral CSA; contralateral = ipsilateral CSA; contralateral < ipsilateral CSA (see Data analysis).

F (1, 80) = 230.9; $p < 0.01$ in the FIM motor score, F (1, 80) = 58.5; $p < 0.01$ in the FIM cognitive score], but no significant *time × group* interaction, indicating the effect of rehabilitation was the same for the 3 groups. *Post hoc* tests showed that there were significant differences in the SIAS affected side motor score at admission and the FIM motor score and the walk velocity at admission and discharge among the 3 groups. Group I had significantly lower SIAS motor score than group III, group III had significantly higher walk velocity than groups I and II at admission and group I at discharge, and group I had significantly lower FIM motor score than groups II and III at admission and discharge.

DISCUSSION

Our study demonstrated that when patients with unilateral hemispheric stroke were analysed as a whole, the paravertebral muscle CSA and CT numbers were significantly greater on the side contralateral to the brain lesion than on the ipsilateral side both at admission and discharge. This was in contrast to the thigh muscles whose CSA and CT numbers were higher on the ipsilateral side. This finding could be interpreted by greater contribution to paravertebral muscle innervation by uncrossed fibres from the unaffected hemisphere as opposed to the predominantly unilateral innervation of limb muscles. Studies using transcortical magnetic stimulation support this hypothesis (10, 11). Ferbert et al. (11) recorded MEP from bilateral paravertebral muscle with unilateral hemispheric stimulation in 9 healthy persons. Plassman & Gandevia (10) also recorded MEP from abdominal muscles ipsilateral to the stimulation side, but less frequently than from the contralateral side. In patients with hemiparesis, Fujiwara et al. (17) found more frequent recording of MEP from ipsilateral paravertebral muscle and external oblique abdominal muscles compared with healthy adults.

However, when analysed as subgroups, 42% of the patients had greater paravertebral muscle CSA and CT numbers on the contralateral side (group I), while in 37% of them they were equal on both sides (group II), and in another 21% of cases, they were greater on the ipsilateral side (group III). This may partly explain why previous studies (12, 13) gave contradictory results as to the side difference of paravertebral muscle. When the degree of side difference was related to the degree of limb paresis (the SIAS motor score), FIM motor score and the walk velocity, patients with greater paravertebral muscle CSA on the contralateral side (group I) tended to have more severe paresis and functional limitation. One possible explanation for this finding might be a difference in the degree of compensatory activation of pre-existing uncrossed pathways from the unaffected hemisphere (17, 18), which was activated differently in each patient according to the degree of the brain damage. Another possibility is suggested from a kinesiological study. Basmajian (27) demonstrated with surface electrode recordings that in more severely affected patients with hemiparetic stroke, the unaffected upper and lower extremities are predominantly used and the trunk is more frequently rotated and laterally flexed to the unaffected side, leading to more frequent activation of the back muscles contralateral to the brain lesion. Therefore, the pattern and degree of trunk muscle activation that occur during daily life and rehabilitation training might contribute to the difference in size between the ipsilateral and contralateral trunk muscles. In any case, our findings indicated the need to consider the degree of limb impairment and disability when comparing bilateral paravertebral muscle in these patients.

Regarding longitudinal changes in CT parameters, several studies are available for leg muscles (28–31), but studies are limited for trunk muscles. For leg muscle, Kondo & Ota (30) found that in bedridden patients with stroke, the CSA decreased progressively not only on the affected side but also on the unaffected side. For the affected side, morphological and histochemical studies (28, 29, 31) suggest that mixed influences of disuse and central factors contribute to the atrophic changes. For the unaffected leg, the role of disuse is emphasized. Odajima et al. (28) reported using CT that the CSA of peripheral leg muscles in non-ambulatory and patients with low ADL were smaller than those in ambulatory and patients with high ADL, and although the atrophic changes and muscle weakness were more marked on the affected side, they were noticeable on the unaffected side as well. Tanaka et al. (29) also concluded that disuse atrophy played an important role by studying the effect of daily activity levels on muscle atrophy and weakness of the unaffected leg.

As for trunk muscles, there are studies (3, 4, 6) that longitudinally analysed the changes of trunk functions with clinical scales. Franchignoni et al. (3) reported improvement in TCT score by approximately 70% and in the Postural Assessment Scale for Stroke Patients established by Benaim et al. (6) by 40% after 1 or 2 months of a rehabilitation program. Our CT study demonstrated that trunk muscle CSA increased bilaterally by 3–4% after a 3-month conventional stroke rehabilitation program. The degree of improvement was much smaller than that observed with clinical scales. This could be because the improvement in clinical scales was brought about not only by an improvement in trunk muscle function but also by improvements in other factors such as spatial neglect and consciousness disturbance.

When compared with leg muscles, whose CSA and CT numbers increased approximately by 20% at discharge on both the affected and unaffected sides, the increase for trunk muscles was much less. One possible explanation might be that bilateral innervation of trunk muscles prevented marked atrophic changes and muscle weakness on the affected side. In a study using transcortical magnetic stimulation, Fujiwara et al. (17) reported that the recovery of trunk function after stroke was associated with an increase in ipsilateral MEP in the trunk muscles upon stimulation of the unaffected hemisphere, and suggested the role of compensatory activation of uncrossed fibres in the recovery of trunk function, as is the case for finger and hand functions (32, 33), swallowing function (34) and lingual function (35). It is postulated that pre-existing uncrossed pathways are unmasked by a decreased intracortical inhibition (18).

In conclusion, paravertebral muscle CSA as measured with CT was greater on the side contralateral to the hemispheric lesion compared with the ipsilateral side, and the difference between the 2 sides was greater in patients with more severe hemiparesis and functional limitation. The difference in the degree of compensatory activation of pre-existing uncrossed pathways from the unaffected hemisphere was suggested as a possible mechanism. Longitudinally, the CSA and CT numbers increased bilaterally with a conventional stroke rehabilitation program. Further studies are needed to determine whether a more intensive program directed to trunk muscle training would be beneficial for these patients.

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