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Effects of Trunk Stabilization Exercises on Different Support Surfaces on the Cross-sectional Area of the Trunk Muscles and Balance Ability

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Abstract. [Purpose] The purpose of this study was to examine the effects on stroke patients of trunk stabilization exercise on different support surfaces. [Subjects and Methods] Sixteen stroke patients with onset of stroke six months earlier or longer were randomly and equally assigned to group I (exercise performed on a stable support surface) and group II (exercise performed on an unstable support surface). The two groups conducted the trunk stabilization exercises on the respective support surfaces, in addition to existing rehabilitation exercises five times per week for 12 weeks. Changes in the cross-sectional area (CSA) of the muscles were examined using computed tomography (CT), and changes in the balance ability were assessed using a measuring system and the trunk impairment scale (TIS). [Results] In group I, there was a significant increase in the CSA of the mulifidus muscle on the side contralateral to the brain lesion and in the paravertebral and multifidus muscles on the side ipsilateral to the brain lesion. In group II, there was a significant increase in the CSA of the paravertebral and multifidus muscles on the side contralateral to the brain lesion and on the side ipsilateral to the brain lesion. In terms of changes in balance ability, the sway path (SP) and TIS significantly improved in group I, and the SP, sway area (SA), and TIS significantly improved in group II . [Conclusion] Exercise on the unstable support surface enhanced the size of the cross-sectional area of the trunk muscles and balance ability significantly more than exercise on the stable support surface.

Key words: Cross-sectional areas, Trunk control, Balance

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INTRODUCTION

The trunk is the center of the body, and it plays a postural role in functional movement by preparing the body for the movement of the extremities against gravity. It also plays an active role in smoothing the movement of the center of gravity, and it enables ease of movement into a new posture[1)]. Balance is the result of interactions among the visual system, vestibular system, proprioceptive system, musculoskeletal system, and cognitive ability. Balance maintenance is a very important element for safe and independent performance in ordinary life of movements and walking[2)].

Stroke patients suffer from balance disability due to abnormalities in the proprioceptive system, sensory system, trunk muscles, and muscles of the limbs[1, 2)]. Stroke often causes paralysis on the affected side as soon as it occurs, decreasing the adjustment ability of the trunk[2, 3)]. In particular, reduction in the activity of the muscles of the trunk reduces movement of the pelvis, leading to the development of asymmetry of the trunk, and preventing use of strategies protecting against the risk of balance loss[4, 5)].

A previous study evaluated the trunk muscles of stroke patients and normal age-matched controls using a hand-held dynamometer and found that stroke patients' bilateral lateral flexors were weaker[6)]. A study that used an isokinetic dynamometer reported that trunk flexors, extensors, and bilateral rotators were weakened in stroke patients[7, 8)]. Stroke patients experience weakened trunk muscles on the unaffected side, as well as the affected side. Therefore, evaluation of the trunk should be made on the affected and unaffected sides.

Verheyden et al.[9)] conducted trunk exercise on a stable support surface with subacute stroke patients and reported that the functions of their trunks improved. Bayouk et al.[10)] observed that exercise on different support surfaces had a positive influence on subacute stroke patients. Shumway-Cook et al.[11)] noted that an unstable support surface stimulated the sensory system and the motor system more than a stable support surface, effectively changing postural ori-

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entation ability and aiding postural strategies. Until now, clinical evaluation tools for the assessment of stroke patients' trunks have been used. However, changes in scores are difficult to interpret. And an additional problem is the potential subjectivity of the evaluators. In contrast, morphological study through computed tomography (CT) enables visual identification of muscles and is quantitative and objective[12)].

Accordingly, in the present study we examined the changes in the cross-sectional area of the trunk muscles using CT and investigated how trunk stabilization exercise affects balance ability. This study also aimed to establish a scientific basis for an effective trunk muscle-training environment for stroke patients.

SUBJECTS AND METHODS

Subjects

The study subjects were 16 stroke patients. Those who were diagnosed with an ischemic or hemorrhagic stroke and whose onset of stroke was six months earlier or longer, who were able to independently sit for longer than 30 seconds, who did not have hemineglect, who were able to understand a therapist's direction and communicate, who were able to perform exercises for 30 minutes or longer, who did not have a medical contraindication against trunk exercise, who had no disease affecting balance, and who had no history of surgery due to musculoskeletal diseases were included in the study. All the subjects provided their voluntary consent before they participated in this study. Data collection was initiated following the approval of Donghin University's Institutional Review Board. Table 1 shows the characteristics of the subjects.

Table 1. Characteristics of study participants

Parameters	Group I (n=8)	Group II (n=8)
Age (years)	53.4±5.8	52.4±7.6
Sex (male/female)	5/3	4/4
Time since onset (months)	17.9±4.3	18.1±4.2
Affected side (right/left)	4/4	3/5
Cause (hemorrhage/ischemic)	2/6	3/5
Trunk Impairment Scale (0–23)	15.80±3.99	14.20±4.26
Modified Ashworth Scale (n)		
1+	6	5
2	2	3

All data are expressed as means with standard deviation (SD).

Methods

Using white and black cards, this study equally assigned the subjects to two experimental groups: group I performed trunk stabilization exercises on a stable support surface, and group II performed trunk stabilization exercises on an unstable support surface. Both groups conducted warming-up exercises for 5 minutes, the main exercise for 20 minutes, and cooling-down exercises for 5 minutes, for a total of 30 minutes, in addition to existing rehabilitation treatment five times per week for 12 weeks.

All the subjects in this study conducted task-specific movement exercises of the upper and lower trunk in the supine and sitting positions based on the revised and complemented version of Verheyden et al.[9)] The two groups conducted exercise according to the method presented in Table 2. Group I conducted all exercises on a stable support surface. Group II conducted all exercises on a physio ball, an unstable support surface. The pelvic bridge and the unilateral bridge performed by group II were initiated with the physio ball in the downward direction.

A physical therapist helped with all the exercises. When the trunk exercise was initiated, the therapist provided a moderate level of aid and gradually reduced the level of support. The number of exercise repetitions and the intensity were based on reducing the base of support, increasing the lever arm, advancing the balance limits, or increasing the hold time[13)].

CT was used to measure the cross-sectional area of the trunk muscles. A cushion was placed beneath the knees with subjects in the supine position, and even weight was maintained on both sides. In this position, the lumber 4 upper end plate, where the curvature angle is smallest and precise imaging is possible, was scanned. A CT 5-mm scan was obtained at a power of 120 kV and 240 mA for 1 second (matrix 512 × 512 pixels). In the cross-sectional area of the muscles, the multifidus, deep muscle, paraspinal muscle, and superficial muscle were measured. Analysis after the measurement was performed on the regions of interest using a picture archiving and communication system. The images were enlarged to 152.28% to enhance the visibility of the circumference of each muscle. A drawing was made along the contour surfaces, avoiding fat, skeletal structure, and other soft tissues. The sum of the cross-sectional areas of the muscles was then automatically calculated by the computer[14)].

Balance ability was measured using BioRescue (RM Ingenierie Co., France). Static balance ability, sway path (SP) and the sway area (SA) were measured with the subjects looking to at the front for 60 seconds on the plate, with their eyes open. To determine the dynamic balance ability, the average speed of the sway (SAP) was measured during rotation of 180 degrees on the plate[15)]. For the clinical assessment, the trunk impairment scale (TIS) was used to evaluate the static, dynamic, and coordination ability of the trunk in the sitting position[16)].

For the statistical analysis, SPSS version 12.0 for Windows was used. The independent t-test was used to compare the cross-sectional areas of the muscles on the side contralateral and ipsilateral to the brain lesion, before and after the trunk stabilization exercises, and the differences in the cross-sectional area and balance ability between the two experimental groups. The paired t-test was used to analyze the size of the cross-sectional area and the balance ability in each group, before and after the trunk stabilization exercises. The statistical significance level was chosen as at α=0.05.

Table 2. Each experimental group's exercise method

Position	Group I	Group II
Supine	Pelvic bridge (raising the pelvis with the soles of the feet on the ground) Unilateral bridge (raising and maintaining the foot on the non-paretic side in a pelvic bridge position) Upper trunk flexion rotation (placing the soles of the feet on the ground and moving the hands diagonally to grab the knees) Lower trunk flexion rotation (placing the soles of the feet on the ground and bringing the pelvis diagonally to the shoulder)	Pelvic bridge (raising the pelvis with both legs on the physio ball) Unilateral bridge (raising and maintaining the foot on the non-paretic side in a pelvic bridge position from the ball) Upper trunk flexion rotation (placing the trunk on the physio ball, bending the knees, placing the soles of the feet on the ground and grabbing an object on the hip joint on the opposite side) Lower trunk flexion rotation (bringing the pelvis diagonally to the shoulder in a pelvic bridge posture)
Sitting	Lower trunk flexion extension (performing anteflexion and retroflexion on the table) Upper trunk lateral flexion (descending the elbow to the table from the shoulder girdle) Lower trunk lateral flexion (raising the pelvis from the table in the direction of ribcage from the pelvic girdle) Upper trunk rotation (moving the shoulders forward and backward) Lower trunk rotation (moving the knees forward and backward) Weight shifting (moving the upper part of the body forward and touching the tops of the feet and moving the upper part backward to a maximum level) Forward reach (forward flexing the trunk and grabbing an object at the height of the shoulders) Lateral reach (grabbing an object at the height of the shoulders by elongating the trunk where the weight is loaded and shortening the opposite trunk)	Lower trunk flexion extension (performing anteflexion and retroflexion on the physio ball) Upper trunk lateral flexion (moving the elbow down to the ball from the shoulder girdle) Lower trunk lateral flexion (raising the pelvis from the ball in the direction of the ribcage from the pelvic girdle) Upper trunk rotation (moving the shoulders forward and backward) Lower trunk rotation (moving the knees forward and backward) Weight shifting (moving the ball forward and touching the tops of the feet and moving the ball backward to a maximum level) Forward reach (forward flexing the trunk and grabbing an object at the height of the shoulders) Lateral reach (grabbing an object at the height of the shoulders by elongating the trunk where the weight is loaded and shortening the opposite trunk)

RESULTS

The cross-sectional areas of the sides contralateral and ipsilateral to the brain lesion were compared before and after the trunk stabilization exercises. In both groups, the cross-sectional areas of the paravertebral and the multifidus muscles on the side contralateral to the brain lesion were larger than on the ipsilateral side ($p<0.05$). Comparison of the before and after results showed that the cross-sectional area of the multifidus muscle ($t=-2.90$, $p<0.05$) significantly increased on the side contralateral to the brain lesion in group I. In addition, the cross-sectional areas of the paravertebral ($t=-3.15$, $p<0.05$) and multifidus muscles significantly increased ($t=-2.60$, $p<0.05$) on the side ipsilateral to the brain lesion in group I. In group II, the cross-sectional areas of the paravertebral ($t=-2.27$, $p<0.05$) and the multifidus muscles ($t=-6.61$, $p<0.05$) significantly increased on the side contralateral to the brain lesion, and the cross-sectional areas of the paravertebral ($t=-3.06$, $p<0.05$) and the multifidus muscles ($t=-3.77$, $p<0.05$) significantly increased on the side ipsilateral to the brain lesion. Comparison of changes in the cross-sectional areas between the two groups revealed that the multifidus muscle ($t=-2.11$, $p<0.05$) significantly differed in the cross-sectional area on the side contralateral to the brain lesion and that the multifidus mucle ($t=-2.12$, $p<0.05$) significantly differed in the cross-sectional area on the side ipsilateral to the brain lesion (Table 2).

Comparison of the balance ability within the two groups for each of the trunk stabilization exercise surfaces showed that group I significantly differed in terms of SP ($t=2.90$, $p<0.05$) and TIS ($t=-2.65$, $p<0.05$), and group II significantly differed in terms of SP ($t=3.02$, $p<0.05$), SA ($t=2.83$, $p<0.05$), and TIS ($t=-3.83$, $p<0.05$) (Table 3).

DISCUSSION

The trunk plays a role in maximizing function and minimizing the weight on the joints during different activities17). However, hemiplegic patients have muscle function loss and resulting balance disorder, which disrupts their daily lives4). To resolve this problem, there are many therapeutic approaches to motion relearning and voluntary adjustment used in rehabilitation treatment18). A few hypotheses have been presented as to the cause of trunk muscle weakening in stroke patients. Neurological control of the trunk is dominated by the bilateral cerebral hemispheres, and a lesion on one side may affect both sides of the trunk. Trunk muscle weakening has been attributed to insufficient mobilization of high-threshold motor units and disuse of muscles2). In hemiplegic patients, the weakening of muscle strength is not severe compared to that of the muscles of the extremities. However, trunk muscles on the paretic and the non-

Table 3. Comparison of the cross-sectional areas between group I and II (Mean±SD)

Parameters		C (mm)	I (mm)	C/I (%)
Group I				
Paravertebral	Pre	4913.80±485.84†	4683.90±570.05	106.41±17.63
	Post	5077.60±704.35	4867.50±578.20*	105.88±21.40
Multifidus	Pre	574.60±97.70†	551.70±106.36	105.38±13.43
	Post	610.30±89.50*	584.40±99.83*	105.49±11.97
Group II				
Paravertebral	Pre	4845.90±592.68†	4533.90±444.63	107.78±17.32
	Post	5096.50±491.08*	4803.50±438.65*	106.87±14.13
Multifidus	Pre	557.00±97.57†	538.30±74.71	104.38±17.70
	Post	688.40±75.70$^{***\#}$	673.30±87.02$^{**\#}$	103.30±13.14

The independent t-test was used to compare differences between the sides contralateral and ipsilateral to the brain lesion before and after the exercise († ; p<0.05), and differences between the two experimental groups ($^{\#}$; p<0.05). The paired t-test was used to compare differences in each group before and after the exercise (*: p<0.05, **: p<0.01, ***: p<0.001).
C: side contralateral to the brain lesion, I: side ipsilateral to the brain lesion

Table 4. Changes of balance between control and experimental group (Mean±SD)

Parameters		Group I		Group II	
		Pre	Post	Pre	Post
Static balance	SP (mm)	233.90±85.20	181.90±56.74*	253.40±73.45	207.90±59.13*
	SA (mm^2)	241.10±64.41	194.60±90.20	252.70±49.89	212.70±50.26*
Dynamic balance	SAP (mm/s)	239.00±70.61	209.30±42.48	231.30±64.27	204.60±57.84
TIS (score)		15.80±3.99	17.60±3.24*	14.20±4.26	17.90±2.88**

The paired t-test was used to compare differences in each group before and after the exercise (*: p<0.05, **: p<0.01).
SP: sway path, SA: sway area, SAP: sway average speed, TIS: trunk impairment scale

paretic sides are weakened19).

To improve the strength of the trunk muscles, the abdominal muscles, and the multifidus muscles, the small muscles of the vertebrae need to be harmoniously activated20). These muscles are tonic or postural muscles and the muscle imbalance necessary for the stability of the trunk and for postural adjustment is improved during whole body exercise21).

When improving the strength of the trunk muscles, an increase in the cross-sectional area of the trunk muscles does not occur during the first four weeks of exercise. The observed increase in muscle strength is due to adaptation in the neurological system. The increase in the strength of the muscles owing to an increase in the cross-sectional area of the muscles occurs eight weeks after the start of exercise22). This study conducted trunk stabilization exercises for 12 weeks on a stable support surface (group I) and on an unstable support surface (group II), with stroke patients whose onset of stroke had occurred six months earlier or longer and determined the effects of the changes in cross-sectional areas of subjects' trunk muscles and their balance.

The tensile force exerted by the muscles exhibits performance of muscle strength in proportion to the cross-sectional area if neurological adaptation is unaffected23). However, in the present study, the subjects had diseases of the central nervous system. Thus, changes in the cross-sectional area of their trunk muscles may not haven been proportionate to changes in muscle strength. Nevertheless, changes in the cross-sectional area may serve as an index that indicates changes in the muscles.

Using CT, this study analyzed the cross-sectional areas of the multifidus, deep stabilizer muscles and the paravertebral, superficial stabilizer muscles by dividing them into those on the side contralateral to the brain lesion and thosed on the side ipsilateral to the brain lesion. The results show that the cross-sectional area of the trunk muscles on the side contralateral to the brain lesion significantly increased after the exercise. Ferbert et al.24) conducted transcortical magnetic stimulation on one hemisphere of normal subjects and the recorded motor evoked potential (MEP) on the bilateral paravertebral. Fujiwara et al.25) conducted transcortical magnetic stimulation on the cerebral hemisphere of stroke patients on the non-paretic side. They found that changes in the MEP of the paravertebral muscles on the contralateral side to the brain lesion were more significant than those of normal subjects. Another study showed that compensatory activities through uncrossed pathways of the unaffected hemisphere are involved in functional recovery of the trunk26).

In the present study, the strength of the trunk muscles improved in the two groups. The results for group I were similar to those of Verheyden et al.9) who conducted trunk exercise on a stable support surface for stroke patients. Comparing the two groups, the improvement in the multifidus, deep muscles, of group II showed the most significant difference. This result suggests that exercise on an unstable support surface is more effective at activating the trunk muscle tissue than that on a stable support surface. In other words, diverse movement on an unstable support surface appears to provide postural perturbation enhancing the maintenance of desired postures[16, 27].

According to Table 3, the C/I of group II was lower than that of group I after the exercise. Thus, the trunk stabilization exercises on the unstable support surface seem to have produced a balanced adjustment in the performance of the muscles on the side contralateral to the brain lesion and on the side ipsilateral to the brain lesion. Voluntary efforts to maintain the desired postures during exercise on an unstable support surface may stimulate activation of the bilateral cerebral cortex.

A recent posturographic analysis reported that stroke patients tended not to move the center of the body to the paretic side while in the sitting and standing positions[28, 29]. Accordingly, we examined the effects of changes in the cross-sectional area of the trunk muscles on balance (Table 4). Balance was enhanced in both groups after the exercise, demonstrating that improvement in proximal trunk adjustment plays a role in improving balance ability. Verhetden et al.[30] also noted that there was positive association between trunk adjustment and balance after stroke. The static balance and the balance ability in the sitting position showed more improvement in group II than in group I. In a posturographic analysis, Messir et al.[5] observed that the lower trunk movements of stroke patients were very limited and that their upper trunk movements were also limited, reducing balance. In the present study, exercise on the unstable support surface improved lower trunk muscle adjustment, increasing the stability of the pelvis and affecting the mobility of the upper trunk and distal lower extremities, thereby improving balance. Therefore, exercise on an unstable support surface provides a superior environment for trunk muscle exercises for stroke patients by increasing the cross-sectional areas of the trunk muscles and improving balance ability.

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