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TRUNK FUNCTION IN HEMIPLEGIC PATIENTS: KINEMATIC ANALYSIS OF TRUNK BENDING AND GAIT PERFORMANCE

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ABSTRACT

Background: Trunk function is considered important for stroke patients in rehabilitation, but the significance of this factoris unclear. In this study, we examined trunk function, defined as the ability to keep the trunk stable against gravity during movement. In addition, we aimed to elucidate the relationship between gait performance and trunk function.

Methods: The subjects were 14 hemiplegic men and 20 healthy elderly men. Movement was assessed by a three-dimensional motion analysis system focusing on the trunk. The trunk was divided into three parts: the pelvis, the middle trunk, and the upper trunk. The parameters assessed were static standing, anterior tilt of the trunk in the standing position, and gait. We examined the relationship of each of these trunk movement factors with gait speed. All data was analyzed using SPSS program version 21 ($p < 0.05$).

Results: Comparing data of hemiplegic patients to that of normal subjects, during trunk bending, a large rotation angle toward the non-affected side was found and that toward the affected side of the middle trunk at the toe off time of the affected limb during gait was found in hemiplegic patients ($p < 0.01$). The degrees of both rotation angles were related to the gait performance.

Conclusion: The movement of the middle trunk during bending in hemiplegic patients affected gait performance. The results indicated that gravity and movements of lower limbs easily affected the middle trunk. This is an important factor to consider in the rehabilitation of hemiplegic patients.

Keywords: kinematics, stroke patients, trunk function, gait performance, motion analysis, rehabilitation.

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INTRODUCTION

Improvement in activities of daily living, especially gait performance is necessary for the social reintegration of hemiplegic patients. In these activities, the functions of the trunk [1-3] and lower extremities [4-9] are thought to be important. During gait, the required functions of lower limbs are propulsion, upright stability, and shock absorption and energy conservation [10]. In hemiplegic gait, these functions are weak due to abnormal muscle tone and synergy movement pattern. For that reason, there is evidence that lower limb function contributes to gait speed and independence. Evaluation methods have been developed for lower extremity function, such as the Brunnstrom Recovery Stage [11], Fugl-Meyer Assessment (FMA), and Manual Muscle Test. However, they cannot be used to evaluate trunk function. Although trunk function is important for the improvement of movement in hemiplegic patients, the contribution of trunk function parameters that affect movement, including mobility, muscle strength, and coordination, is unknown. Trunk function is typically evaluated using the Trunk Impairment Scale (TIS)[12], Trunk Control Test [13], and Functional Assessment for Control of Trunk [14]. These assessments only measure that the patients can or cannot do some performances, the results are difficult to inform therapists about the cause that make difficult to do performances.

In the literature on gait, it has been proposed that the trunk is a passenger unit, in that it is a part of the body that is carried by the locomotor unit of the lower limbs [10]. During normal gait, it is only necessary for the muscles of the neck and trunk to maintain the spine at a neutral position. From this perspective, trunk function appears to be a relatively unimportant requirement for satisfactory gait. However, some reports have noted that trunk function influenced gait performance [3,15]and activities of daily living [1,2] in hemiplegic patients. Further, another previous study showed that trunk training improved gait performance and balance when standing [16]. In this research context, we thought that the effect of trunk function on gait should be clarified in hemiplegic patients.

Activities of daily living are improved more quickly than gait performance in hemiplegic patients. In daily life, trunk bending is necessary when reaching and when moving from a sitting position to a standing position. During trunk bending, the range of bending is controlled through the erector spinae muscles [17] and coordination is necessary between the erector spinae muscles, the multifidus lumborum and transversus abdominis of the lower trunk muscles [18]. The activity of these trunk muscles is more necessary during trunk bending than is the case during static posture, since the effect of gravity is increased as the trunk bends. During gait, it is important to maintain the trunk in a stable upright position, which requires the activity of trunk muscles. There are reports that loss of selective activity in trunk fails to enable the thoracic spine in extension while using lower abdominals, which is reflected in walking [19,20]. This function is also necessary in other activities of daily living. Therefore, we decided to focus on trunk bending as a means of investigating the patients' ability to support their trunks against gravity.

In the studies about hemiplegic patients, grand reaction force, Gait Abnormality Rating Scale, Wiscinsin Gait Scale, and gait speed evaluated the gait performance. Speed above a certain level is required to gait outside independently in patients. For this reason, in this study, it was used gait speed as gait performance.

The purposes of this study were to examine trunk function using a three-dimensional motion analysis system and to clarify the effect of trunk function on the gait of hemiplegic patients. Here, we defined trunk function as the ability to keep the trunk stable against gravity during forward bending. In addition, we aimed to elucidate the relationship between gait performance and trunk function.

METHODS

Subjects

Fourteen hemiplegic patients and 20 healthy elderly control subjects participated in this study (Table1). The current study only included men because differences in breast size among women can introduce biases into three-dimensional measurements and analysis of trunk position. All patients could stand independently for at least 10 seconds. The control group was restricted to elderly individuals who did not have any orthopedic, neuromuscular, or neurological conditions, and did not have any problems performing the activities of daily living.

The FMA was used to evaluate the motor and sensory function of the lower extremities, and TIS was used to evaluate trunk function in hemiplegic patients. The Functional Independence Measure was used to assess the patients' activity levels. The general characteristics of the cases of hemiplegia are shown in Table2.

Table-1: Participant characteristics

	Healthy participants (n=20)	Hemiplegic patients (n=14)
Age	79.3±2.6	59.2±10.5**
Height (mm)	1633.0±50.0	1638.0±93.0
Weight (kg)	60.2±9.4	63.3±13.0

***p<0.01*

Results are expressed as mean ± standard deviation.

Table-2: General characteristics of the cases of hemiplegia

	Value (range or number)
Days after onset	104.8±54.9 (53-210)
Type of stroke	Cerebral hemorrhage (6)/ Cerebral infarction (8)
Affected side	Right (8)/Left (6)

Measurement protocol

We used two motion laboratories to measure posture and motion: one laboratory included a three-dimensional motion analysis system(VICON NEXUS, Vicon Motion SystemsLtd., UK.) and six force plates (AMTI, USA),while the other included a VICON MX (Vicon Motion Systems Ltd., UK) and four force plates (Kyowa Electronic Instruments Co., Japan). Static standing, trunk bending during standing, and gait were measured at a sampling rate of 100Hz (VICON NEXUS) and 120Hz (VICON MX). Markers were attached to the body on both sides of the acromion, coracoid process, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter, knee joint, lateral malleolus, fifth metatarsal bone head and supra sterna notch, second thoracic spinous process, T8, xiphoid process, and T10.

Before the measurement, the participants practiced their movements several times. After the practice, we performed the measurements of the static standing position. During static standing, the participants were instructed to look straight ahead and relax, but no instruction was given regarding the angles of their feet or the widths between their feet. In addition, we instructed the participants to cross their arms in front of their chests. After confirming that one of the markers was hidden when viewed on the monitor, we began to collect measurements. Because we thought that the loading rate of the affected lower limb could influence movement in hemiplegic patients, we calculated the ground reaction force. Measurements were recorded for 10 seconds.

For the measurements of trunk bending, the participants were instructed to bend the trunk from the hip joint to approximately 30° and to maintain this posture for 2-3 seconds. The actual bending angle depended on each participant's subjective decision. The bending movement was repeated five times.

For the measurements of gait, the participants were instructed to walk at a comfortable speed. The participants were allowed to use braces or a cane if this was necessary to avoid the risk of falling. We obtained five cycles of walking data on the right side of the healthy participants and the affected side of the hemiplegic patients. The right leg was chosen because it was not the dominant leg in all healthy elderly subjects who participated in this study.

Data processing

The upper trunk segment was defined using the markers on the coracoid process, second thoracic spinous process, and suprasterna notch and the pelvis segment were defined using the markers on the ASIS and PSIS. The middle trunk segment was difficult to define because it was easily deformed. Therefore, to observe the movement of the middle trunk, we defined a straight line that connected the xiphoid process and the T8. It was reported that the skin marker at single thoracic vertebrae as T8 resulted in scare repeatability [21]. But, in other studies, T2 and the midpoint between caudal points of the two scapulae were used to define a trunk segment [22,23]. There is the midpoint around T7 and T8. And we have thought that this position, T8 is approximately a center of upper body mass and also a point of inspection for movements. Therefore, T8 marker was selected. The angles of forward inclination and rotation of the three parts of the trunk were measured and calculated. These angles were measured with respect to the absolute coordinate system of the laboratory. A positive value indicated forward tilt and rotation to left side in the elderly individuals, and rotation to the non-affected side in the hemiplegic patients.

For the measurement of standing posture, the average angles and vertical component of the ground reaction force were calculated from 3 to 6 seconds after the start of the measurement.

Regarding the measurement of the trunk bending movement, the starting position of bending was defined as the position in which the suprasternal notch marker was at its minimum forward location in the sagittal plane. The maximum bending position was defined as the position in which the suprasternal notch marker was at its maximum forward location. For each part of the trunk, the angles during bending motion were calculated as the change from the angles that had been measured during static standing. We used an average of the data from five repetitions in our analysis.

For the measurement of gait, the same parameters as the trunk bending movement were calculated. The angles of the trunk were extracted at initial contact (IC: right side and affected side), toe off (TO) for the contra lateral lower extremity (opposite-TO: left side and non-affected side-TO), IC of the contra lateral lower extremity (opposite-IC: left side and non-affected side-IC), and toe off (TO: right side and affected side-TO).In our analysis, we used averages of the data from five repetitions, taken at four different points of the gait.

Statistical analysis

To analyze the differences between healthy elderly individuals and hemiplegic patients, the Mann-Whitney U test was used. To examine the relationships between angle features during bending and gait, the Spearman correlation coefficient was used. The correlation coefficients between these angles and gait speed were calculated. A p-value <0.05 was regarded as indicating statistical significance. In our results, continuous variables were summarized as means ± standard deviations.

Table-3: Clinical data of hemiplegic patients

Clinical test	Value (range or number)
Functional Independence Measure score	110.7±16.7 (71-123)
Fugl-Meyer score (motor)	24.1±6.6 (14-34)
Fugl-Meyer score (sensory)	7.1±4.4 (1-12)
Trunk Impairment Scale score	13.7±5.3 (7-21)
Means of ambulation in the hospital	wheelchair (6)/gait (8)

Results are expressed as mean ± standard deviation.

RESULTS

The FMA and TIS results of the hemiplegic patients are shown in Table3. Gait speed was 0.91±0.17m/s in the healthy elderly participants and 0.47±0.30m/s in the hemiplegic patients ($p<0.01$).

In static standing, only the forward tilt of the middle trunk significantly differed between healthy elderly individuals and hemiplegic patients (7.6±5.8° vs. 15.7±7.9°; $p<0.01$). The vertical component of the ground reaction force was 49.6±4.8% on the left side of the healthy elderly individuals and 61.5±11.9% on the non-affected side of the hemiplegic patients ($p<0.01$).

For trunk bending in the standing position, various differences were observed between the groups. The tilt angles of the three parts were smaller in the hemiplegic patients than in the healthy elderly individuals, but the rotation angles were larger (Table 4). This increased rotation angle was due to rotation to the non-affected side. In particular, the rotation angle of the middle trunk was larger in the hemiplegic patients than in the healthy elderly individuals. The vertical component of the ground reaction force during trunk bending did not fluctuate from the values observed during static standing in either of the two groups.

In gait analysis, we noted distinct features at IC and TO. At IC, the forward tilt angle of the pelvis and middle trunk was larger in hemiplegic patients than in healthy individuals. The rotation angle of the middle trunk differed between healthy elderly and hemiplegic patients at TO. As shown in Table5, the rotation angle of the middle trunk revealed rotation to the left side (toward the forward limb) at TO in the healthy individuals. However, the middle trunk showed rotation to the affected side (toward the backward limb) in hemiplegic patients (Table5). No difference was found at the opposite-TO or the opposite-IC.

We found a negative correlation between the rotation angle of the middle trunk at bending and gait speed($r=-0.71$, $p<0.01$). There was a positive correlation between the rotation angle of the middle trunk at TO of the affected side and gait speed. This positive correlation indicated that a large rotation angle of the middle trunk to the affected side was associated with a slower gait speed ($r=0.60$, $p<0.05$). However, no corresponding correlation was seen in healthy elderly individuals (Table 6).Moreover, in hemiplegic patients, the rotation angle of the middle trunk during trunk bending was related to the rotation of the middle trunk at TO of the affected side ($r= -0.77$, $p<0.01$).

Table-4: Tilt and rotation angles of the trunk during bending

Parameters	Segment	Healthy participants (n = 20)	Hemiplegic patients (n = 14)
Tilt angle	Upper trunk	47.1±9.0°	43.6±9.0°**
	Middle trunk	45.3±8.0°	41.4±9.4°**
	Pelvis	25.1±8.9°	20.0±7.3°**
Rotation angle	Upper trunk	1.1±1.8°	2.5±4.6°**
	Middle trunk	0.9±2.1°	4.8±6.0°**
	Pelvis	1.6±2.0°	2.1±5.5°**

$^{**}p<0.01$

Results are expressed as mean ± standard deviation.

A positive value of the tilt angle indicates forward tilt. For the healthy participants, a positive value of the rotation angle indicates rotation to the left side. For the patients with hemiplegia, a positive value of the rotation angle indicates rotation to the non-affected side.

Table-5: Tilt and rotation angles of the trunk during gait

The period of gait	Parameters	Healthy participants (n = 20)	Hemiplegic patients (n = 14)
R/affected side IC	Tilt angle of the upper trunk	5.2±4.4°	3.3±4.1°
	Tilt angle of the middle trunk	3.8±3.2°	1.3±3.2°*
	Tilt angle of the pelvis	0.3±2.6°	-3.3±5.1°*
	Rotation angle of the upper trunk	–0.6±3.4°	-2.1±5.5°
	Rotation angle of the middle trunk	0.6±3.8°	-1.4±5.8°
	Rotation angle of the pelvis	4.6±5.0°	2.9±5.6°
L/non-affected side TO	Tilt angle of the upper trunk	4.5±4.4°	3.9±5.6°
	Tilt angle of the middle trunk	2.8±3.2°	2.7±3.4°
	Tilt angle of the pelvis	-0.7±2.3°	-0.6±4.0°
	Rotation angle of the upper trunk	0.0±2.6°	-0.2±4.2°
	Rotation angle of the middle trunk	0.6±2.8°	-0.1±4.4°
	Rotation angle of the pelvis	4.5±3.7°	1.9±4.8°
L/non-affected side IC	Tilt angle of the upper trunk	5.0±4.1°	5.5±7.4°
	Tilt angle of the middle trunk	3.5±3.1°	5.0±4.1°
	Tilt angle of the pelvis	0.1±2.5°	1.2±4.4°
	Rotation angle of the upper trunk	3.0±3.3°	0.6±3.6°
	Rotation angle of the middle trunk	2.5±3.6°	0.2±3.5°
	Rotation angle of the pelvis	-1.6±3.5°	-2.3±4.4°
R/affected side TO	Tilt angle of the upper trunk	3.8±4.5°	5.9±5.1°
	Tilt angle of the middle trunk	2.3±3.4°	3.7±4.3°
	Tilt angle of the pelvis	-0.78±2.3°	0.2±4.6°
	Rotation angle of the upper trunk	1.9±4.0°	-3.0±5.1°**
	Rotation angle of the middle trunk	2.2±4.3°	-3.7±5.1°**
	Rotation angle of the pelvis	-1.8±4.0°	-4.0±4.9

$^{*}p<0.05$, $^{**}p<0.01$

Results are expressed as mean ± standard deviation.

A positive value of the tilt angle indicates forward tilt. For the health participants, a positive value of the rotation angle in-

dicates rotation to left side. For the patients with hemiplegia, a positive value of the rotation angle indicates rotation to the non-affected side.

Table-6: Correlations between the tilt and rotation angles of the trunk and gait speed

Movement	Parameters	Healthy participants	Hemiplegic patients
Trunk bending	Tilt angle of the upper trunk	0.05	0.23
	Tilt angle of the middle trunk	0.05	0.16
	Tilt angle of the pelvis	0.41	-0.05
	Rotation angle of the upper trunk	-0.24	-0.47
	Rotation angle of the middle trunk	-0.13	-0.71** 1)
Gait	(IC) Tilt angle of the middle trunk	0.05	0.16
	(IC) Tilt angle of the pelvis	0.41	-0.05
	(TO) Rotation angle of the upper trunk	0.17	0.31
	(TO) Rotation angle of the middle trunk	0.17	0.60* 2)

$^{*}p<0.05$, $^{**}p<0.01$

Results are expressed as mean ± standard deviation.

The signs of the angles are the same as in Tables 4 and 5.

1) A negative correlation indicates that, during trunk bending, larger rotations of the middle trunk toward the affected side were correlated with slower gait speeds.

2) A positive correlation indicates that, during gait, larger rotations of the middle trunk toward the affected side were correlated with slower gait speeds.

DISCUSSION

Standing is the most common active position in movement and work [24]. As the middle part of the body, the trunk is important to maintaining posture when standing. Patients with hemiplegia have impaired balance and performance during daily activities [25]. In our analysis of static standing, we found that the middle trunk was tilted forward to a greater extent in hemiplegic patients than in healthy elderly individuals. Only the lumbar vertebrae and the lower thoracic spine are present between the pelvis and the middle trunk, where as a rigid rib cage is present in the upper trunk. In hemiplegic patients, the part of the trunk with less rigidity between the pelvis and middle trunk, lumbar spine, is considered to have low capacity of keeping against gravity.

In the analysis of trunk bending, the amount of forward bending was observed to be reduced in all parts of the trunk in hemiplegic patients. Trunk bending requires a greater anti-gravity extension capacity of the trunk than the static standing. In this study, although the effects of physical sensations could not be excluded, we found that the hemiplegic patients had a lower extension-maintaining capacity of the trunk against gravity, particularly in the middle trunk. In previous studies, it has been shown that trunk muscle function differs between the affected and non-affected sides in hemiplegic patients [26, 27] and is reduced during lateral and forward flexion of the trunk [28]. These findings are similar to that of our study. In this study, most patients had chronic hemiplegia, and therefore also had a characteristic asymmetric posture, which was likely attributable to greater use of the trunk muscles on the non-affected than on the affected side.

This study showed the relationship between the rotation angle of the middle trunk during trunk bending and that at TO of the affected side while walking. At TO, the trunk is placed in front of the affected foot, and the affected hip joint starts to flex toward the swing phase from extension in terminal stance. During flexion of the hip joint at TO, the role of the iliopsoas is very important. In the iliopsoas, a force is generated in late stance in eccentric contraction [29], and when the non-affected foot contacts the floor, the accumulated force is released. At TO, the iliopsoas shortens and pulls the femur to the lumbar vertebrae. At this point, the activity of the iliopsoas pulls the trunk forward and downward, making it necessary for the trunk to act against gravity. However, the iliopsoas is characteristically shortened in hemiplegic patients. In hemiplegic patients, the iliopsoas cannot extend in late stance, which causes the pelvis and lumbar vertebrae to come closer to the femur in late stance and at TO. In addition, hemiplegic patients have frequently limitation of range at ankle and hip joint. These influence a discrepancy between the front of a trunk and the direction of a gait. Therefore, the affected middle trunk rotates to the affected side. This rotation of the middle trunk inhibits the increase of the gait speed. Consequently, speed reduces.

Our study has some limitations. Trunk muscle activity could not be determined; hence, analysis by using electromyography is needed in the future. And we focused only trunk, the capacity of affected lower limb is not considered. Furthermore, the sample size was small, and it was not possible to include women because of limitations to the process for measuring three-dimensional position. To confirm our findings, further studies with a larger sample size are needed to examine results for women, onset data, damage to areas of the brain, and the ability to perform activities of daily living.

CONCLUSION

During trunk bending, the angle of forward tilt at the middle trunk was smaller and the rotation angle to the non-affected side was larger in hemiplegic patients than in healthy individuals. The extent of rotation of the middle trunk in trunk bending was related to the extent of rotation of the middle trunk at TO. Further, the extent rotation of the middle trunk in trunk bending was related to the gait speed.

Our results show that the position of the middle trunk, that is lumbar vertebrae, which is important to maintaining against gravity, is a factor that can be considered in the improvement of gait ability in hemiplegic patients. In addition, we found that trunk tilt was an indicator of trunk function and gait in hemiplegic patients.

Ethical audit

This study was approved by the ethical committees of the International University of Health and Welfare (No. 20010-3), Bunkyo Gakuin University (No. 10-27), and the director of Nakaizu Rehabilitation Center. Written informed consent was obtained from all participants before participation.

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