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Original Article

Relationship between trunk stability during voluntary limb and trunk movements and clinical measurements of patients with chronic stroke

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Abstract. [Purpose] The purposes of this study were to investigate differences between patients with chronic stroke and age matched healthy controls in trunk stability, by assessing the kinematics of the center of mass and moving body segments during voluntary limb and trunk movement, and the relationship between trunk stability and clinical measurements. [Subjects and Methods] Fifteen stroke patients and 15 age- and gender-matched healthy subjects participated. Each subject performed flexion of the hip and shoulder of the non-paretic or matched side as fast as possible, as well as trunk flexion and extension at a self-selected speed. A Qualisys motion system was employed to track the kinematics of the trunk and limbs. [Results] Patients presented larger mediolateral displacement of the center of mass during all limb and trunk movements, and larger velocity of center of mass during hip flexion movement. Healthy subjects showed greater movement velocity during shoulder flexion, trunk flexion and extension. Patients' clinical measurements only correlated with movement characteristics during voluntary trunk motions. [Conclusion] Trunk stability in patients with chronic stroke was compromised during voluntary trunk as well as non-paretic limb movements, and the voluntary trunk movements reflected the trunk deficits measured using clinical measurements. Rehabilitation of patients with chronic stroke should include programs to improve trunk stability.

Key words: Stroke, Trunk stability, Kinematics

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INTRODUCTION

Residual motor-sensory impairments and disability afflicting patients who have had a stroke are not limited to the limbs/trunk functions are affected as well[1–3)]. Previous studies have used sitting balance to predict post-stroke motor functions[4, 5)]. A strong positive correlation was found between sitting balance and the Berg Balance Scale after stroke[4)]. A balanced sitting score combined with the motor function of the arm at 1 week post stroke was found to reliably predict motor function after discharge[5)]. Good sitting balance is based on proper trunk control. Post-stroke trunk function measured by different clinical scales has been shown to predict outcomes of activities of daily living[6)], mobility[7)], and walking ability[8)]. Thus, adequate trunk control is crucial for this population.

The trunk participates in movements involving the trunk itself and/or the limb(s). For example, trunk muscles function as stabilizers immediately prior to or during limb movements[9–12)], or as prime movers in voluntary trunk movements[13–15)]. Anticipatory postural adjustment resulting from the provision of internal perturbation has been suggested in patients with stroke[11, 12)]. During leg flexing or arm raising movements, post-stroke patients have been shown to exhibit bilaterally delayed activation of the trunk muscles compared to healthy controls[12)]. During symmetrical voluntary trunk flexion movements, patients have also been shown to exhibit delayed and reduced muscle activation[15)]. No difference has been found in recruitment latencies during trunk extension between patients and control subjects, but patients have exhibited delayed EMG activation on the paretic side compared to the nonparetic side. Patients have shown motor impairment in the activity of trunk muscles in previous studies. However, it is not clear whether impair-

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ment of the neuromuscular control of the trunk affects motor performance, such as the displacement and velocity of the center of mass (COM) or limbs. Displacement of the COM reflects the ability of the central nervous system to maintain postural stability in feedforward postural control tasks[16, 17]. Thus, it is important to elucidate kinematic COM displacement behavior, post-stroke, during anticipatory postural adjustment.

The purposes of this study were to investigate differences between patients with chronic stroke and age-matched healthy controls in the trunk stability, by assessing the kinematics of the center of mass and moving body segments during voluntary limb and trunk movement, and the relationship between trunk stability and clinical measurement.

Table 1. Characteristics of STROKE and CONTROL

Characteristics	STROKE	CONTROL
Age (years)	50.3 ± 7.7	50.4 ± 8.1
Gender (male/female)	7/8	7/8
Years since stroke	4.6 ± 4.7	
Hemiparesis side (right)	10	
Infarction stroke	9	
MMSE (score)	28.1 ± 2.4	
Barthel index (score)	98.7 ± 2.3	
TIS (score)	16.6 ± 4.2	
PASS (score)	31.4 ± 2.9	

MMSE: Mini-Mental status examination; TIS: Trunk Impairment Scale; PASS: Postural Assessment Scale for Stroke Patients

SUBJECTS AND METHODS

Stroke patients (STROKE) were recruited from a hospital in Kaohsiung City, Taiwan. The inclusion criteria were: first time stroke patients with unilateral hemiplegia or hemiparesis who were medically stable over 6 months, ability to follow three-step commands, ability to sit independently, and no other neuromuscular diseases or vestibular dysfunctions. Age and gender-matched healthy control subjects (CONTROL) were also recruited from communities in Kaohsiung City. The study protocol was approved by the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital, Kaohsiung, Taiwan. Each subject signed an informed consent before participating in the study.

The initial assessment of STROKE included collecting basic information (Table 1), a physical examination, stroke-related conditions (onset, lesion site, lesion type), mental status (Mini-Mental Status Examination, MMSE), function of daily living (Barthel index, BI), motor impairment (Trunk Impairment Scale, TIS), and a balance test (Postural Assessment Scale for Stroke Patients, PASS). The assessment of the postural control tasks was conducted in the second session (about 3 hours). For CONTROL, all tests were completed in one session (approximately 3 hours).

A six-camera motion analysis system (Qualisys Oqus, Qualisys Medical AB, Partille, Sweden) was used to record body kinematics during trunk movement tasks. Reflective markers were attached over anatomical landmarks according to the guidelines of the Visual 3D kinematics model (C-motion, USA).

Trunk as a stabilizer: From a sitting position, the subjects performed, as fast as possible, non-paretic shoulder flexion to 90° (UE-F) or non-paretic hip flexion (LE-F) until the foot was 3 cm above the ground when verbal cues were provided by the examiner, and the subject was instructed to hold the trunk in position during the movements.

Trunk as a prime mover: The subjects folded their arms and moved at a self-selected speed. In the trunk flexion condition (TF), the subjects sat on a chair with a reclining back allowing them to lie backward at a thigh to trunk angle of 130°. The subjects were asked to perform trunk flexion to the upright position upon hearing the verbal cue to do so. For the trunk extension condition (TE), the subject leaned forward until the folded arms touched the thighs. The subject then performed trunk extension to the upright position without pushing the arms against the thighs.

The COM was calculated without the lower limbs to reflect the effects of specific movements on trunk stability. 3D displacement and COM velocity, the markers on the moving segments and the angular velocity of the moving parts were calculated using the Visual 3D software. Programs written in the Matlab platform (The MathWorks Inc., Natick, MA, USA) were used to calculate variables of interest. The ranges of COM in the anteroposterior (COM-ap) and mediolateral (COM-ml) directions were calculated. A positive value of maximal displacement in the mediolateral direction (COM-ml-max) indicates that the subject was moving on the non-paretic side during the motion, and a negative value indicates the movement was on the paretic side. The maximum tangential velocity values of the COM (COM-velocity) and the following markers (Marker-velocity) were calculated during the trunk and limb movement tasks: 1st-MTP, wrist marker, C7, and jugular notch. Sagittal angular-velocities (Angular-velocity) of the hip, shoulder, and trunk were also computed during the LE-F, UE-F, TE and TF. The mean values of three trials were used in all analyses.

All statistical analyses were conducted using SPSS for Windows, version 17 (SPSS Inc. Armonk, NY, USA). Significance was accepted for values of $p< 0.05$. Data sets with normal distributions are presented as means and standard deviations, and those without normal distributions are presented as medians and percentiles. The independent t test and the nonparametric Mann-Whitney U test were used to investigate differences in the variables between STROKE and CONTROL. Either a Pearson correlation or a Spearman correlation was used to test the association between the COM variables and the clinical measurements, including TIS and PASS.

RESULTS

Fifteen patients (average height: 162.7±7.8 cm, average weight: 71.3±12.9 kg) and 15 healthy, age-match control subjects (average height: 164.9±7.1 cm, average weight: 65.8±10.4 kg) participated in this study. The demographic and clinical characteristics of STROKE and CONTROL are shown in Table 1. There was no significant difference in the ages of the two groups.

Table 2. Comparison of movement variables between the two groups during all 4 trunk tasks

	STROKE	CONTROL
LE-F		
COM-ap (cm) [b]	0.825–2.856 (1.210)	0.409–1.404 (0.692)
COM-ml (cm) [b, *]	0.456–1.209 (0.758)	0.270–0.521 (0.375)
COM-ml-max (cm) [a, *]	−0.766 (0.487)	−0.185 (0.370)
COM-velocity (cm/s) [b, *]	13.407–28.871 (19.707)	3.111–12.067 (7.722)
Marker-velocity (cm/sec) [a]	26.629 (12.218)	24.553 (12.840)
Angular-velocity (degree/sec) [b]	16.345–41.794 (28.136)	14.836–29.543 (24.988)
UE-F		
COM-ap (cm) [b]	0.769–1.129 (0.997)	0.980–1.439 (1.078)
COM-ml (cm) [a, *]	1.519 (0.540)	1.176 (0.305)
COM-ml-max (cm) [a]	−1.476 (0.540)	−1.083 (0.586)
COM-velocity (cm/s) [b]	10.497–28.522 (21.572)	10.376–39.412 (24.982)
Marker-velocity (cm/sec) [a]	182.015 (60.206)	215.038 (57.353)
Angular-velocity (degree/sec) [b, *]	167.735–227.465 (193.348)	180.412–284.650 (212.462)
TE		
COM-ap (cm) [a]	18.358 (5.233)	20.927 (4.104)
COM-ml (cm) [b, *]	0.699–1.786 (0.916)	0.551–1.025 (0.610)
COM-ml-max (cm) [a]	−0.430 (1.323)	0.231 (0.549)
COM-velocity (cm/s) [b, *]	26.699–59.560 (36.722)	39.017–68.675 (60.913)
Marker-velocity (cm/s) [b]	36.005–67.702 (54.601)	50.959–79.311 (60.170)
Angular-velocity (degree/sec) [a]	58.168 (20.865)	72.257 (31.595)
TF		
COM-ap (cm) [a]	16.986 (3.299)	18.058 (4.600)
COM-ml (cm) [b, *]	0.880–1.356 (1.130)	0.504–1.100 (0.892)
COM-ml-max (cm) [a]	−0.180 (1.054)	−0.316 (1.313)
COM-velocity (cm/s) [b]	19.830–70.351 (27.592)	19.801–31.191 (28.991)
Marker-velocity (cm/s) [b, *]	21.825–32.449 (28.697)	27.419–47.781 (37.367)
Angular-velocity (degree/sec) [b]	46.990–62.436 (57.334)	48.144–83.932 (55.396)

* $p<0.05$
[a] Normally distributed data expressed as mean (SD).
[b] Mann-Whitney U test. Data without a normal distribution are presented as the range of the 25th and 75th percentiles (median).

In the LE-F task, there were significant differences between STROKE and CONTROL in COM-ml and COM-ml-max, as shown in Table 2 (Z=−3.049, p=0.002, and t=−3.684, p=0.001). STROKE showed a larger COM-velocity (Z=−3.215, p=0.001). During the UE-F, there were significant differences between the groups in COM-ml and Angular-velocity (t=2.139, p=0.044 and Z=−2.053, p=0.040). Compared with UE-F, trunk instability during the LE-F was more severe in STROKE. In TE, there were significant differences between the groups in COM-ml and COM-velocity (Table 2, Z=−2.592, p=0.010 and Z=−2.344, p=0.019). There were no significant group differences in COM-ap, COM-ml-max, Marker-velocity, or Angular-velocity. In the TF task, STROKE exhibited a larger COM-ml (Z=−2.012, p=0.044), and slower Marker-velocity (Z=−1.970, p=0.049).

Overall, there was no significant correlation between movement variables and clinical measurements in LE-F or UE-F in STROKE (Table 3). The TIS score positively correlated with the Angular-velocity and COM-ml-max in TE. The PASS score was statistically associated with the COM-velocity in TF.

DISCUSSION

Kinematic analysis provides insight into the motor behavior of patients with central nervous system damage regarding control of the trunk in different roles and demands during movement, and the trunk as a stabilizer or as a prime mover. In the present study, STROKE were middle-aged individuals with a high level of function of daily activities (BI mean 98.7/ 100), cognitive ability (MMSE mean 28.1/ 30), and moderate to very good trunk control ability (TIS mean 16.6/ 23). Despite the fact that the patients had these characteristics, they showed impaired ability to control the trunk during voluntary non-paretic limb and trunk movements.

Hip or shoulder flexion had been used as a source of postural perturbation to study anticipatory postural adjustment using electromyography in healthy subjects and in stroke patients[18–21]. Kinematics is an important aspect of movement and it also reflects the outcomes of postural control. The findings of the present study fill the gap in the results for COM range in the frontal plane, and COM-velocity in LE-F, as well as Angular-velocity in UE-F. STROKE showed a

Table 3. Correlation coefficients between COM variables and the clinical measurements of STROKE

		COM-ap	COM-ml	COM-ml-max	COM-velocity	Marker-velocity	Angular-velocity
LE-F	TIS	−0.023	−0.432	0.275[a]	0.456	0.115[a]	0.391
	PASS	0.047	−0.398	0.158	0.499	0.094	0.127
UE-F	TIS	−0.124	−0.065[a]	0.100[a]	0.066	−0.224[a]	−0.488
	PASS	−0.136	−0.169	0.182	0.247	0.316	0.185
TE	TIS	0.033[a]	−0.185	0.593[a, *]	0.170	0.014	0.529*
	PASS	−0.105	−0.256	0.417	0.034	−0.178	0.352
TF	TIS	−0.173[a]	−0.337	0.276[a]	0.027	0.185	0.143
	PASS	0.060	−0.047	0.211	0.588*	0.333	0.036

* $p<0.05$

[a] Pearson correlation coefficients were used to test normally distributed data.

larger COM-ml under both the LE-F and UE-F conditions. One previous study presented differences in EMG temporal synchronization (rectus abdominis and external oblique) between groups in flexion of the paretic as well as the nonparetic hips[12)]. This previous study also reported that the rectus abdominis and external oblique muscles showed higher activity levels on the nonparetic side, regardless of the side of the hip flexion movement[12)]. These two muscles are regarded as belonging to the global stabilizing system of the trunk[22)]. They have large muscle masses and long moment arms which provide larger and more powerful movements than muscles of the local stabilizing system. Unilateral rectus abdominis and external oblique muscle contractions produce lateral trunk flexion and rotation motions. For the UE-F condition, the effects of the lower extremities on postural control can be diminished by adopting a sitting position. The present study focused on trunk postural control in the sitting position by calculating the COM without the lower limbs. The muscle activation of the latissimus dorsi has been shown to be smaller on the paretic side than on the nonparetic side, and in normal subjects during shoulder flexion and shoulder abduction[11, 12)]. Attached to the core of the trunk, the latissimus dorsi connects the thoracolumbar fascia, which serves as an anchor stabilizing the trunk during shoulder movement[23, 24)]. Although a verbal command was given to the subjects to hold the trunk in position, in the present study, STROKE showed postural instability in the frontal plane.

Speed may represent the effects of postural instability in subjects with hemiplegia[25)]. The speed of a moving limb reflects the ability to generate either fast or slow movement, and the velocity of the center of foot pressure reflects the body's reaction to perturbation[26)]. In the current study, STROKE showed larger COM-velocity than that of CONTROL during LE-F. The absence of a significant difference in the Marker-velocity indicates that STROKE had the ability to generate a speed as fast as that of CONTROL. Higher velocity of hip movement might cause a larger perturbation and affect the maintenance of balance. STROKE might have failed to control the trunk in as stable a manner as CONTROL, resulting in a higher COM-velocity and larger COM-ml. These results were similar to those of a previous study[26)]. This previous study reported that patients with hemiplegia, despite slower arm movement, had higher center of pressure excursion speeds than both older and younger subjects. As for UE-F, in the present study, STROKE had a slower Angular-velocity. This finding of slower moving limbs in stroke patients is consistent with the findings of previous studies[11, 12)]. However, unlike the findings for LE-F, no difference was found in COM-velocity. Therefore, the perturbation generated by slower arm movement might be small in STROKE. In addition, the variability of COM-velocity in CONTROL was larger, which might mean that normal controls have the flexibility to adopt different movement strategies during shoulder flexion movement[27)].

STROKE showed the same postural instability as they did in the trunk stabilized conditions as evidenced by the smaller Marker-velocity during TF. In addition, smaller COM-velocity during TE accompanied by larger COM-ml was found in stroke patients compared to CONTROL. There are no reported COM data to compare with the results of the present study, and only one previous study has reported that patients perform TF and TE at a significantly lower velocity than healthy subjects[15)]. Compared to the lateral and distal muscles, the axial and proximal muscles received bilateral hemispheric input to a greater extent[28–30)]. In patients with stroke, stimulation of the intact hemisphere has been shown to evoke bilateral trunk responses, and the ipsilateral motor-evoked potentials of stroke patients have been shown to increase in comparison to those of control subjects[31)]. Compensatory activation of the hemiplegic side has been shown to appear after a stroke[32)]. However, the performance of the trunk muscle has been shown to be compromised at maximal muscle strength[33, 34)] and submaximal muscle strength[35)]. In the current study, COM didn't shift to a specific side in either group during symmetrical movements, but STROKE showed a larger COM-ml. Stroke patients did show postural instability during symmetrical trunk movements.

The Angular-velocity during TE significantly correlated with the TIS in STROKE. Larger trunk Angular-velocity was associated with higher TIS scores, that is, better trunk control ability. To better fit the need for assessing stroke outcomes, the TIS tests static sitting balance, dynamic sitting balance, and trunk coordination[36)]. It also evaluates the quality of movement by observing both compensatory and selective trunk movements during sitting and has been reported to correlate with ADL, gait performance and other clinical measures[2, 8, 37–38)]. The TIS may possibly reflect a different ability to generate velocity in STROKE, which is also important for transition in postural tasks, such as when moving from sitting to standing[39]. The results of the present study support the proposition that the TIS is valid for use in the clinical assessment of the trunk control of stroke patients. In TF, COM-velocity correlated with the PASS score, which was developed to evaluate the ability of stroke patients to maintain both posture and equilibrium when changing position[40]. One of the items on the PASS is intended to evaluate a patient's performance moving from a supine position to a sitting position. Although the position of the leg during TF was not the same as that in the supine-to-sit movement, the fact that the subjects had to contract their abdominal muscles during TF is similar to the activity required in the supine-to-sit movement. This might be the reason why the larger COM-velocity during TF was associated with better postural control as evaluated by the PASS. The lack of significant correlations between clinical measurements and LE-F or UE-F might indicate they measured different aspects of control ability in STROKE suggesting that voluntary trunk movements would better reflect the deficits measured by clinical measurements.

A limitation of this study was that generalization of the results to patients whose conditions were not similar to those of the stroke patients participating in this study, such as patients with low functional scores of activity of daily living, low cognitive ability, or low trunk control scores, should be done with caution. It will be necessary to investigate larger samples in future studies so that the differences in trunk control between patients with various motor impairments and healthy subjects can be revealed. Despite the restricted generalization, the patients without severe dysfunction showed trunk instability during voluntary limb and trunk movements.

In the case of patients with chronic stroke, the trunk stability measures represented by the range of COM in the frontal plane and movement velocity were compromised not only during voluntary non-paretic limb movements but also during voluntary trunk movements. Movement characteristics during voluntary trunk motions, especially the COM displacement in the mediolateral direction and the velocity of the COM of the trunk, were associated with the TIS and PASS scores. During rehabilitation of chronic stroke patients, clinicians should pay attention to patients' trunk control ability.

REFERENCES

1) Cruz TH, Lewek MD, Dhaher YY: Biomechanical impairments and gait adaptations post-stroke: multi-factorial associations. J Biomech, 2009, 42: 1673–1677. [Medline] [CrossRef]
2) Verheyden G, Nieuwboer A, De Wit L, et al.: Time course of trunk, arm, leg, and functional recovery after ischemic stroke. Neurorehabil Neural Repair, 2008, 22: 173–179. [Medline] [CrossRef]
3) Fujita T, Sato A, Togashi Y, et al.: Contribution of abdominal muscle strength to various activities of daily living of stroke patients with mild paralysis. J Phys Ther Sci, 2015, 27: 815–818. [Medline] [CrossRef]
4) Suzuki M, Fujisawa H, Machida Y, et al.: Relationship between the Berg balance scale and static balance test in hemiplegic patients with stroke. J Phys Ther Sci, 2013, 25: 1043–1049. [Medline] [CrossRef]
5) Loewen SC, Anderson BA: Predictors of stroke outcome using objective measurement scales. Stroke, 1990, 21: 78–81. [Medline] [CrossRef]
6) Hsieh CL, Sheu CF, Hsueh IP, et al.: Trunk control as an early predictor of comprehensive activities of daily living function in stroke patients. Stroke, 2002, 33: 2626–2630. [Medline] [CrossRef]
7) Franchignoni FP, Tesio L, Ricupero C, et al.: Trunk control test as an early predictor of stroke rehabilitation outcome. Stroke, 1997, 28: 1382–1385. [Medline] [CrossRef]
8) Verheyden G, Vereeck L, Truijen S, et al.: Trunk performance after stroke and the relationship with balance, gait and functional ability. Clin Rehabil, 2006, 20: 451–458. [Medline] [CrossRef]
9) Hodges P, Cresswell A, Thorstensson A: Preparatory trunk motion accompanies rapid upper limb movement. Exp Brain Res, 1999, 124: 69–79. [Medline] [CrossRef]
10) Hodges PW, Richardson CA: Relationship between limb movement speed and associated contraction of the trunk muscles. Ergonomics, 1997, 40: 1220–1230. [Medline] [CrossRef]
11) Palmer E, Downes L, Ashby P: Associated postural adjustments are impaired by a lesion of the cortex. Neurology, 1996, 46: 471–475. [Medline] [CrossRef]
12) Dickstein R, Shefi S, Marcovitz E, et al.: Anticipatory postural adjustment in selected trunk muscles in post stroke hemiparetic patients. Arch Phys Med Rehabil, 2004, 85: 261–267. [Medline] [CrossRef]
13) Dickstein R, Heffes Y, Laufer Y, et al.: Activation of selected trunk muscles during symmetric functional activities in poststroke hemiparetic and hemiplegic patients. J Neurol Neurosurg Psychiatry, 1999, 66: 218–221. [Medline] [CrossRef]
14) Dickstein R, Sheffi S, Ben Haim Z, et al.: Activation of flexor and extensor trunk muscles in hemiparesis. Am J Phys Med Rehabil, 2000, 79: 228–234. [Medline] [CrossRef]
15) Dickstein R, Shefi S, Marcovitz E, et al.: Electromyographic activity of voluntarily activated trunk flexor and extensor muscles in post-stroke hemiparetic subjects. Clin Neurophysiol, 2004, 115: 790–796. [Medline] [CrossRef]
16) Li X, Aruin AS: The effect of short-term changes in body mass distribution on feed-forward postural control. J Electromyogr Kinesiol, 2009, 19: 931–941. [Medline] [CrossRef]
17) Massion J: Movement, posture and equilibrium: interaction and coordination. Prog Neurobiol, 1992, 38: 35–56. [Medline] [CrossRef]
18) Bleuse S, Cassim F, Blatt JL, et al.: Effect of age on anticipatory postural adjustments in unilateral arm movement. Gait Posture, 2006, 24: 203–210. [Medline] [CrossRef]
19) Allison GT, Morris SL, Lay B: Feedforward responses of transversus abdominis are directionally specific and act asymmetrically: implications for core stability theories. J Orthop Sports Phys Ther, 2008, 38: 228–237. [Medline] [CrossRef]
20) Gray VL, Juren LM, Ivanova TD, et al.: Retraining postural responses with exercises emphasizing speed poststroke. Phys Ther, 2012, 92: 924–934. [Medline] [CrossRef]
21) Fishman MN, Colby LA, Sachs LA, et al.: Comparison of upper-extremity balance tasks and force platform testing in persons with hemiparesis. Phys Ther, 1997, 77: 1052–1062. [Medline]
22) Borghuis J, Hof AL, Lemmink KA: The importance of sensory-motor control in providing core stability: implications for measurement and training. Sports Med, 2008, 38: 893–916. [Medline] [CrossRef]
23) Young JL, Herring SA, Press JM, et al.: The influence of the spine on the shoulder in the throwing athlete. J Back Musculoskeletal Rehabil, 1996, 7: 5–17. [Medline] [CrossRef]
24) Kibler WB, Press J, Sciascia A: The role of core stability in athletic function. Sports Med, 2006, 36: 189–198. [Medline] [CrossRef]
25) Yu J, Jung J, Cho K: Changes in postural sway according to surface stability in post-stroke patients. J Phys Ther Sci, 2012, 24: 1183–1186. [CrossRef]
26) Garland SJ, Stevenson TJ, Ivanova T: Postural responses to unilateral arm perturbation in young, elderly, and hemiplegic subjects. Arch Phys Med Rehabil, 1997, 78: 1072–1077. [Medline] [CrossRef]
27) Newell KM: Motor skill acquisition. Annu Rev Psychol, 1991, 42: 213–237. [Medline] [CrossRef]
28) Palmer E, Ashby P: Corticospinal projections to upper limb motoneurones in humans. J Physiol, 1992, 448: 397–412. [Medline] [CrossRef]
29) Ferbert A, Caramia D, Priori A, et al.: Cortical projection to erector spinae muscles in man as assessed by focal transcranial magnetic stimulation. Electroencephalogr Clin Neurophysiol, 1992, 85: 382–387. [Medline] [CrossRef]
30) Carr LJ, Harrison LM, Stephens JA: Evidence for bilateral innervation of certain homologous motoneurone pools in man. J Physiol, 1994, 475: 217–227. [Medline] [CrossRef]
31) Fujiwara T, Sonoda S, Okajima Y, et al.: The relationships between trunk function and the findings of transcranial magnetic stimulation among patients with stroke. J Rehabil Med, 2001, 33: 249–255. [Medline] [CrossRef]
32) Misawa S, Kuwabara S, Matsuda S, et al.: The ipsilateral cortico-spinal

tract is activated after hemiparetic stroke. Eur J Neurol, 2008, 15: 706–711. [Medline] [CrossRef]
33) Tanaka S, Hachisuka K, Ogata H: Muscle strength of trunk flexion-extension in post-stroke hemiplegic patients. Am J Phys Med Rehabil, 1998, 77: 288–290. [Medline] [CrossRef]
34) Bohannon RW, Cassidy D, Walsh S: Trunk muscle strength is impaired multidirectionally after stroke. Clin Rehabil, 1995, 9: 47–51. [CrossRef]
35) Hyngstrom AS, Kuhnen HR, Kirking KM, et al.: Functional implications of impaired control of submaximal hip flexion following stroke. Muscle Nerve, 2014, 49: 225–232. [Medline] [CrossRef]
36) Verheyden G, Nieuwboer A, Mertin J, et al.: The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. Clin Rehabil, 2004, 18: 326–334. [Medline] [CrossRef]
37) Bae SH, Lee HG, Kim YE, et al.: Effects of trunk stabilization exercises on different support surfaces on the cross-sectional area of the trunk muscles and balance ability. J Phys Ther Sci, 2013, 25: 741–745. [Medline] [CrossRef]
38) Jijimol G, Fayaz RK, Vijesh PV: Correlation of trunk impairment with balance in patients with chronic stroke. NeuroRehabilitation, 2013, 32: 323–325. [Medline]
39) Chou SW, Wong AM, Leong CP, et al.: Postural control during sit-to stand and gait in stroke patients. Am J Phys Med Rehabil, 2003, 82: 42–47. [Medline] [CrossRef]
40) Benaim C, Pérennou DA, Villy J, et al.: Validation of a standardized assessment of postural control in stroke patients: the Postural Assessment Scale for Stroke Patients (PASS). Stroke, 1999, 30: 1862–1868. [Medline] [CrossRef]