Decreased Respiratory Muscle Function Is Associated with Impaired Trunk Balance among Chronic Stroke Patients: A Cross-sectional Study

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The abdominal muscles play a role in trunk balance. Abdominal muscle thickness is asymmetrical in stroke survivors, who also have decreased respiratory muscle function. We compared the thickness of the abdominal muscles between the affected and less affected sides in stroke survivors. In addition, the relationship between respiratory muscle function and trunk balance was evaluated. Chronic stroke patients (18 men, 15 women; mean age, 58.94 ± 12.30 years; Mini-Mental Status Examination score ≥ 24) who could sit without assist were enrolled. Abdominal muscle thickness during rest and contraction was measured with ultrasonography, and the thickening ratio was calculated. Respiratory muscle function assessment included maximum respiratory pressure, peak flow, and air volume. Trunk function was evaluated using the Trunk Impairment Scale, and trunk balance was estimated based on the center of pressure velocity and path length within the limit of stability in sitting posture. Abdominal muscles were significantly thinner on the affected side, and the thickening ratio was lower in the affected side ($P < 0.05$). In addition, the higher thickening ratio of the affected side showed significant relationship with higher trunk function. Moreover, higher respiratory muscle function was significantly correlated with higher level of trunk function and balance in stroke patients ($P < 0.05$). Thus, chronic stroke survivors have decreased abdominal muscle thickness on the affected side, and respiratory muscle function has positive correlation with trunk function and balance. We propose that respiratory muscle training should be included as part of trunk balance training in chronic stroke patients.

Keywords: forced expiration; inspiration; respiratory muscle function; stroke; trunk balance.
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Introduction

Unilateral paralysis induced by stroke impairs muscle control and body movement, leading to poor sitting balance and sitting in unusual or asymmetrical positions. Stroke patients lose the ability to perform reaching tasks and encounter difficulty while sitting and standing (Tessem et al. 2007). Moreover, most patients with hemiplegia have difficulty controlling the trunk while adjusting posture. Stroke patients show a considerably reduced level of trunk performance compared to healthy individuals of the same age and sex (Verheyden et al. 2005).

Forced expiratory and inspiratory muscles play a dual role in breathing and trunk balance during exercise (Kawabata et al. 2014). Post-stroke patients have impaired respiratory function as a consequence of muscular weakness and postural trunk dysfunction (Annoni et al. 1990). All forced expiratory and inspiratory muscles can influence trunk balance. An important factor in trunk balance is the voluntary co-contraction of forced expiratory and inspiratory muscles (Tayashiki et al. 2016). The transversus abdominis (TrA), internal oblique (IO), external oblique (EO), and rectus abdominis (RA) are forced expiratory muscles (Akuthota et al. 2008; Tayashiki et al. 2016) and are found in the trunk (Neumann 2010). The diaphragm is a trunk stabilizer (McGill 2001) and a major inspiratory muscle (Neumann 2010).

There is a significant decrease in maximum expiratory and inspiratory pressure in post-stroke patients, compared to that in healthy individuals (Lanini et al. 2003). Moreover, stroke patients (n = 23) showed approximately 40% below of pulmonary function that predicted from age-

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and sex-adjusted norms for sedentary individuals (Macko et al. 2001). Thus, stroke weakens the forced expiratory and inspiratory muscles, which in turn may influence trunk balance. However, it is unclear if the thickness of these abdominal muscles is associated with forced expiratory and inspiratory muscle function and whether these functions have relationship with trunk balance in chronic stroke patients.

Therefore, the aims of this study were to compare the thickness of the abdominal muscles between the affected and less affected sides, to determine whether the difference is present in resting and contraction states, and to determine the relationship between the thickening ratio of the abdominal muscles and trunk function in chronic stroke patients. We also investigated the correlation between respiratory muscle function and trunk balance.

Methods

Participants

The study included 33 chronic stroke patients who volunteered to participate. A physical assessment and interview were initially conducted for all subjects to collect anthropometric and demographic data. A summary of the general characteristics of subjects is provided in Table 1.

All patients provided written informed consent before and after the experiment. Inclusion criteria were as follows: (1) a first stroke, whether ischemic or hemorrhagic (not requiring surgery), over 6 months prior (chronic phase); (2) Mini-Mental Status Examination score ≥ 24; (3) no facial palsy, to minimize bias produced by leakage of air at the mouthpiece when respiratory muscle function is evaluated; (4) no receptive aphasia; and (5) no prior thoracic or abdominal surgery. Exclusion criteria were as follows: (1) use of medication for neuromuscular control or medication that caused drowsiness; (2) evidence of lung disease based on volume; (3) Trunk Impairment Scale score < 10 (Cabanas-Valdes et al. 2016); and (4) musculoskeletal deficit affecting the spine and pelvic girdle (Preuss and Popovic 2010). The study protocol was approved by the institutional review board of Myongji Choonhey Rehabilitation Hospital (MJCHIRB-2016-01) and Sahmyook University (2-1040781-AB-N-01-2016038HR) in Seoul, Republic of Korea. The protocol of this study was approved by the World Health Organization International Clinical Trials Registry Platform (KCT0002048).

Table 1. General characteristics (n = 33).

Sex	
Male/Female (%)	18 (54.5)/15 (45.5)
Age (years)	58.94 ± 12.30
Height (cm)	165.56 ± 9.53
Weight (kg)	65.41 ± 11.56
BMI (kg/m^2)	23.74 ± 3.34
Onset duration (month)	10.84 ± 2.41
MMSE (score)	27.41 ± 1.99
TIS (score)	
Static	5.19 ± 1.31
Dynamic	4.69 ± 1.87
Coordination	1.06 ± 0.35
Total	10.94 ± 2.92
Affected side	
Right/Left (%)	16 (48.5)/17 (51.5)
Type	
Infarction (%)/Hemorrhage (%)	15 (45.5)/18 (54.5)

Values represents mean ± SD.
BMI, body mass index; MMSE, mini-mental status examination; TIS, Trunk Impairment Scale.

Study design

We performed this observational, quantitative, and descriptive study in the Myongji Choonhey Rehabilitation Hospital between June and September 2016.

Abdominal muscle thickness

To evaluate the thickness of abdominal (forced expiratory) muscles, TrA, IO, EO, and RA were measured at the end of expiration (resting) and at maximum forced expiration (contraction). Subjects were positioned in the crook-lying position. Real-time B-mode (MYSONO US, Samsung Medicine, Korea) ultrasonography was used to measure muscle thickness with a 7.5-MHz linear transducer. Muscle imaging was prepared by applying gel to the transducer, which was placed on the lateral abdominal wall without any pressure. The transducer was placed just superior to the iliac crest in the transverse plane along the midaxillary line (Stetts et al. 2009). At this location, ultrasonography images of TrA, IO, and EO muscle thickness can be obtained on a single screen (Fig. 1A). Measurements were performed on the affected and less affected side. For RA, the transducer was placed 2-3 cm above the umbilicus (Tahan et al. 2016). Images of the resting RA were captured at the end of expiration and with maxim expiration to obtain contraction thickness (Fig. 1B). The thickening ratio was calculated as a percentage, using the following formula (Ferrari et al. 2014):

$$\text{Thickening ratio (\%)} = \frac{\text{(Thickness at maximum forced expiration} - \text{Thickness at end of expiration)}}{\text{Thickness at end of expiration}} \times 100$$

The patient was placed in the crook-lying position to examine the diaphragm (inspiratory muscle). The transducer was positioned on the chest wall at the anterior axillary line, just caudal to the lower costal margin (Harper et al. 2013). With the transducer perpendicular to 2 ribs, the diaphragm can be visualized as a hypoechoic layer of muscle covered in 2 hyperechoic layers of the parietal pleura and the peritoneum, deep to the intercostal muscles connecting the 2 ribs (Lanini et al. 2003). On each image, diaphragm thickness was measured from the middle of the pleural line to the middle of the peritoneal line (Boon et al. 2013) (Fig. 1C). Resting diaphragm thickness was measured at the end of expiration, and contraction thickness was measured at maximum inspiration. The thickening ratio was calculated as a percentage using the following formula (Ferrari et al. 2014):

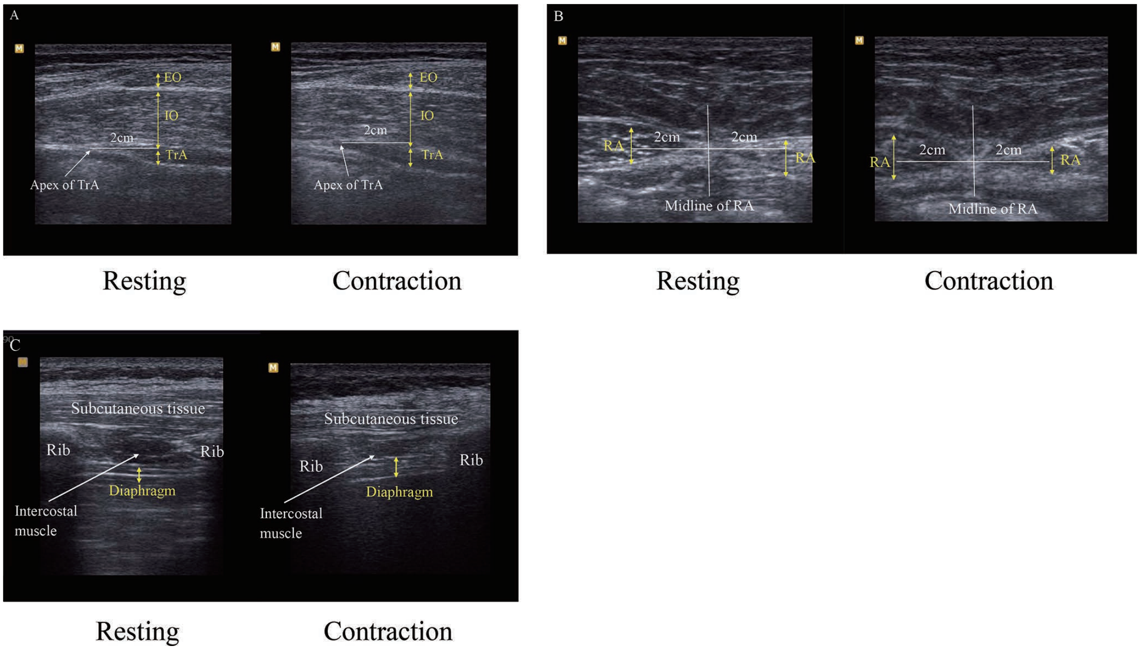

Fig. 1. Ultrasonography images and abdominal muscle thickness measurement.
(A) Abdominal muscle thickness was evaluated using ultrasonography in resting and contraction states. With the transducer placed just superior to the iliac crest in the transverse plane along the midaxillary line, ultrasonography images of TrA, IO, and EO muscle thickness can be obtained in a single screen. (B) RA muscle thickness can be obtained with the transducer placed 2-3 cm above the umbilicus. (C) When the diaphragm image is captured with the transducer perpendicular to 2 ribs, the diaphragm can be visualized as a hypoechoic layer of muscle covered in 2 hyperechoic layers of the parietal pleura and peritoneum, deep to the intercostal muscles connecting the 2 ribs.
TrA, transversus abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.

$$\text{Thickening ratio (\%)} = \frac{\text{(Thickness at maximum inspiration} - \text{Thickness at end of expiration)}}{\text{Thickness at end of expiration}} \times 100$$

The analysis of all images was performed using Sante DICOM Viewer FREE 4.0.14 to determine abdominal muscle thickness.

Respiratory muscle function

Maximum expiratory pressure (MEP), peak expiratory flow (PEF), and forced expiratory volume in 1 second (FEV1) were measured to evaluate forced expiratory muscle function. MEP was evaluated with a handheld mouth pressure meter (MPM, Micro Medical, Kent, UK), and PEF and FEV1 were assessed using a handheld peak flow meter (Microlife PF 100) in the sitting position (Fig. 2A and B) (Yeldan et al. 2008; Messaggi-Sartor et al. 2015). Patients were seated on a chair with feet on the ground and without trunk support, with the trunk at a 90° angle to the hips. A personalized mouthpiece and conventional nose clip were used. Patients could choose their breathing frequency, but were instructed to perform forced and deep expiration followed by complete maximum inspiration (vital capacity, VC) to the end of expiratory reserve volume (ERV). Subjects were given strong verbal encouragement but no visual feedback. They performed a minimum of 3 trials and the best value was used. They were allowed to practice twice and immediately afterwards were asked to repeat the trial until 3 acceptable measurements were obtained (Neder et al. 1999). Measurements were considered acceptable if they were maintained, showed no air leak, lasted for at least 1 s, and when 2 readings were taken with a maximum difference of 10%. Between measurements, a 10-min time was allowed to minimize bias for the MEP, PEF, and FEV1. The highest values were used for analyses.

Maximum inspiratory pressure (MIP), peak inspiratory flow (PIF), and VC were measured using an electronic inspiratory loading device (PowerBreathe K5, 2010, HaB International Ltd., UK) to determine inspiratory muscle function (Lee et al. 2016). The device provides automatically processed information on MIP, PIF, and VC during loaded inspiration tasks (Fig. 2C). With the patient in the same position and instructed to perform forced and deep inspiration followed by complete maximum expiration, i.e., end of ERV to VC, the values were recorded for analysis. Signals from the pneumotachograph were captured electronically using J-Lab software version 5.22.1.50 (Cardinal Health GmbH, Hoechberg, Germany). The respiratory muscle functions are summarized in Table 2.

Trunk balance

Trunk function was assessed with the Trunk Impairment Scale (TIS) (Verheyden et al. 2004), which includes Static, Dynamic, and Coordination components. Trunk balance was evaluated based on the maximum center of pressure (COP) velocity and COP path length of the trunk within the limit of stability during trunk flexion, extension, and bending to the affected and less affected sides. We used the Nintendo Wii Balance Board (WBB) with a Bluetooth-equipped laptop and a software program (Balancia v 2.0, Minto systems, Seoul, Republic of Korea) for signal attainment and examination, respectively (Park and Lee 2014). The WBB was placed on a wooden board

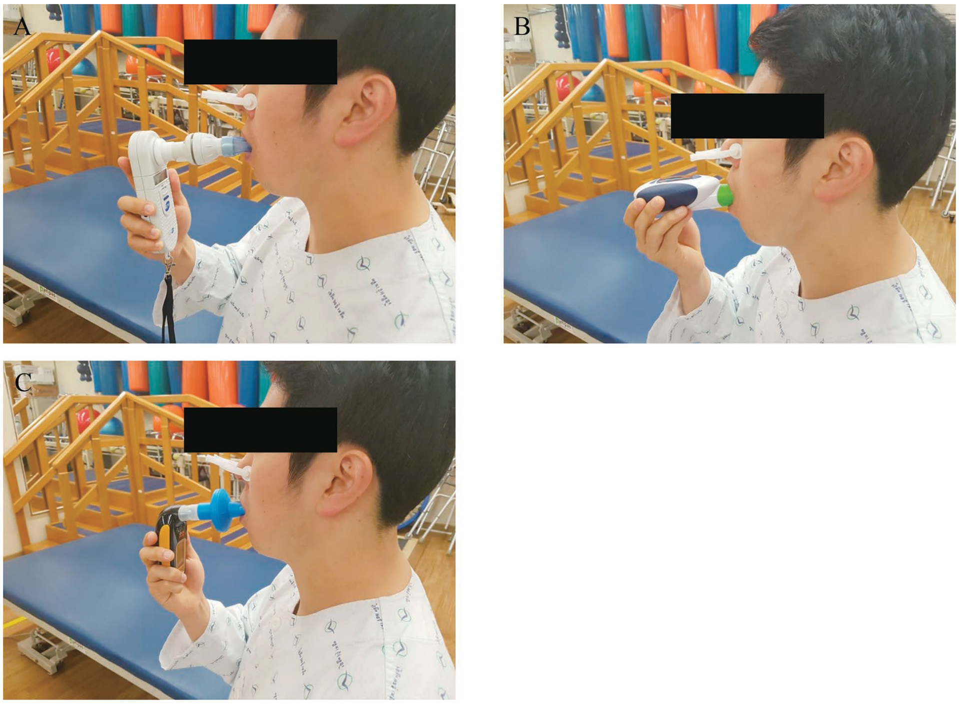

Fig. 2. Devices for measurement of respiratory muscle function.
(A) MEP was evaluated with a handheld mouth pressure meter and (B) PEF and FEV1 were assessed using a handheld peak flow meter to determine forced expiratory muscle function. (C) MIP, PIF, and VC were measured using an electronic inspiratory loading device to define inspiratory muscle function.
MEP, maximum expiratory pressure; PEF, peak expiratory flow; FEV1, Forced expiratory volume in 1 second; MIP, maximum inspiratory pressure; PIF, peak inspiratory flow; VC, vital capacity.

Table 2. The parameters of respiratory muscle functions of this study.

Parameters	
Forced expiratory muscle functions	Maximum expiratory pressure (cmH_2O)
	Peak expiratory flow (ℓ/s)
	Forced expiratory volume in 1 second (ℓ)
Inspiratory muscle functions	Maximum inspiratory pressure (cmH_2O)
	Peak inspiratory flow (ℓ/s)
	Vital capacity (ℓ)

on the floor and subjects were asked to sit on the WBB, with the sacrum 1 cm from the posterior edge of the board (Fig. 3). Initially, the subject moved the trunk twice in 4 directions as instructed by the examiner to provide feedforward for the test procedure. Patients were asked to maintain sitting position on the WBB with the arms crossed on the chest. Thereafter, they moved the trunk and head as fast and as far as possible following the verbal cue of the examiner in random order. Trunk flexion, extension, and bending to the affected and less affected sides were measured at the endpoint of the limit of trunk stability, and the software automatically acquired maximum COP velocity and path length data. Each trial was performed only after a sufficient period of rest to minimize any potential effects of fatigue.

Statistical analysis

All statistical analyses were performed using the PASW statistical package, version 18.0 (SPSS Inc., Chicago, IL, USA). The general characteristics of the subject and variables followed a normal distribution. All variables of the study had a parametric distribution. The paired t-test was used to compare abdominal muscle thickness at rest and during contraction. Pearson's correlation was used to analyze the relationship between TIS, abdominal muscle thickness, respiratory muscle function, and trunk balance for COP velocity and path length during trunk flexion, extension, and bending to the affected and less affected sides in the sitting position. Results were considered significant at a P value of < 0.05.

Results

Among the forced expiratory muscles (Table 3), the TrA was significantly thinner on the affected side compared to the less affected side at rest and during contraction (P < 0.01, P < 0.05, respectively). EO thickness at rest was significantly thinner on the affected side than on the less affected side (P < 0.05). Moreover, the resting and contraction thickness of the inspiratory muscle, i.e., the diaphragm, was significantly less on the affected side (P < 0.001, P < 0.01, respectively). The thickening ratio between rest and contraction in the EO was significantly higher on the affected side than on the less affected side (Table 3).

Fig. 3. Evaluation of trunk balance.
Trunk balance was evaluated based on COP velocity and COP path length of the trunk within the limit of stability during trunk flexion, extension, and bending to the affected and less affected side. WBB with a Bluetooth-equipped laptop and a software program were used for signal attainment and examination, respectively. Patients were asked to maintain sitting position on the WBB, and to move their trunk and head as fast and as far as possible following the verbal cue of the examiner. Trunk flexion, extension, and bending to the affected and less affected side were measured at the endpoint of the limit of trunk stability, and the software automatically acquired maximal COP velocity and path length data.
COP, center of pressure; WBB, Nintendo Wii Balance Board.

The IO muscle thickening ratio on the affected side and the Static component score of the TIS showed positive relationship (r = 0.358, P < 0.05) (Table 4). The diaphragm thickening ratio of the affected (r = 0.402, P < 0.05) and less affected sides (r = 0.369, P < 0.05) and the Dynamic component score of the TIS showed significant positive relationship. The thickening ratio of the less affected side of the diaphragm and the Coordination component score of the TIS had relationship (r = 0.445, P < 0.05). The thickening ratio of the affected side (r = 0.389, P < 0.05) and less affected side (r = 0.424, P < 0.05) of the diaphragm and total TIS score demonstrated relationship (Table 4).

The Static component score of the TIS showed positive relationship with MEP (r = 0.386, P < 0.05) and PIF (r = 0.354, P < 0.05) (Table 5). The Dynamic component score of the TIS had positive relationship with MEP, PEF, FEV1, MIP, and PIF (r = 0.452-0.593, P < 0.05) and the Coordination component score of the TIS demonstrated positive relationship with MIP (r = 360, P < 0.05). The total TIS score, there was positive relationship with MEP, PEF, FEV1, MIP, PIF, and VC (r = 0.369-0.595, P < 0.05) (Table 5).

MEP had positive relationship with COP velocity of extension (r = 0.615, P < 0.01, Fig. 4) and bending to the affected side (r = 0.561, P < 0.01) and less affected side (r = 0.472, P < 0.01) and with COP path length of extension (r = 0.685, P < 0.001, Fig. 4) and bending to the affected side (r = 0.453, P < 0.01) (Table 6). PEF showed positive rela-

Table 3. Abdominal muscle differences between affected and less affected sides (n = 33).

	Resting thickness (cm)			Contraction thickness (cm)			Thickening ratio (%)		
	AS	LAS	P-value	AS	LAS	P-value	AS	LAS	P-value
Forced expiratory muscles									
TrA	0.18 ± 0.05	0.21 ± 0.05	**0.001**	0.24 ± 0.07	0.29 ± 0.09	**0.002**	38.44 ± 21.60	42.18 ± 46.00	0.948
IO	0.50 ± 0.13	0.52 ± 0.13	0.538	0.67 ± 0.15	0.70 ± 0.17	0.260	35.40 ± 24.37	36.92 ± 17.76	0.733
EO	0.23 ± 0.07	0.26 ± 0.07	**0.050**	0.31 ± 0.09	0.32 ± 0.09	0.613	33.20 ± 20.90	21.46 ± 15.58	**0.013**
RA	0.57 ± 0.20	0.55 ± 0.20	0.428	0.67 ± 0.19	0.68 ± 0.21	0.813	21.74 ± 29.77	27.31 ± 29.67	0.153
Inspiratory muscle									
Diaphragm	0.22 ± 0.05	0.28 ± 0.06	**0.001**	0.38 ± 0.11	0.46 ± 0.14	**0.002**	77.64 ± 44.48	73.02 ± 51.85	0.639

Values represent mean ± SD.
AS, affected side; LAS, less affected side; TrA, transversus abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.
Values in bold are significant.

Table 4. Correlations between the Trunk Impairment Scale and thickening ratio of abdominal muscles (n = 33).

		Thickening ratio									
		Affected side					Less affected side				
		TrA	IO	EO	RA	Diaphragm	TrA	IO	EO	RA	Diaphragm
Trunk Impairment Scale											
Static	r	0.328	**0.358**	0.267	0.237	0.226	0.279	0.184	–0.016	0.168	0.296
	P-value	0.067	**0.044**	0.139	0.192	0.214	0.122	0.314	0.931	0.358	0.099
Dynamic	r	0.325	0.239	–0.126	–0.038	**0.402**	0.048	0.084	–0.037	0.162	**0.369**
	P-value	0.070	0.188	0.493	0.834	**0.022**	0.792	0.646	0.841	0.376	**0.038**
Coordination	r	0.097	0.148	–0.185	0.073	0.245	0.034	–0.029	–0.162	0.148	**0.445**
	P-value	0.597	0.420	0.311	0.692	0.177	0.853	0.873	0.375	0.419	**0.011**
Total	r	**0.367**	0.331	0.017	0.090	**0.389**	0.160	0.133	–0.051	0.197	**0.424**
	P-value	**0.039**	0.064	0.928	0.623	**0.028**	0.381	0.468	0.784	0.279	**0.016**

TrA, transversus abdominis; IO, internal oblique; EO, external oblique; RA, rectus abdominis.
Values in bold are significant.

Table 5. Correlations between the Trunk Impairment Scale and respiratory muscle function (n = 33).

		Forced expiratory muscle function			Inspiratory muscle function		
		MEP	PEF	FEV1	MIP	PIF	VC
Trunk Impairment Scale							
Static	r	**0.386**	0.281	0.291	0.346	**0.354**	0.304
	P-value	**0.029**	0.119	0.106	0.053	**0.047**	0.090
Dynamic	r	**0.593**	**0.453**	**0.425**	**0.591**	**0.585**	0.316
	P-value	**0.000**	**0.000**	**0.015**	**0.000**	**0.000**	0.078
Coordination	r	0.344	0.346	0.255	**0.360**	0.343	0.247
	P-value	0.054	0.052	0.159	**0.043**	0.055	0.172
Total	r	**0.595**	**0.459**	**0.434**	**0.578**	**0.576**	**0.369**
	P-value	**0.000**	**0.008**	**0.013**	**0.001**	**0.001**	**0.038**

MIP, maximum inspiratory pressure; PIF, peak inspiratory flow; VC, vital capacity; MEP, maximum expiratory pressure; PEF, peak expiratory flow; FEV1, forced expiratory volume in 1 s.
Values in bold are significant.

tionship with COP velocity of bending to the affected and less affected side ($r = 0.447$, $P < 0.05$; $r = 0.452$, $P < 0.01$; respectively) and with COP path length of extension ($r = 0.615$, $P < 0.001$) (Table 6). In FEV1, there was positive relationship with COP velocity of bending to the affected and less affected side ($r = 0.522$, $P < 0.01$; $r = 0.574$, $P < 0.01$; respectively) and with COP path length of extension ($r = 0.648$, $P < 0.001$). MIP demonstrated weak to positive relationship with COP velocity of flexion, extension, and bending to the affected and less affected side ($r = 0.363$-0.651, $P < 0.05$) (Table 6) and with COP path length of extension ($r = 0.683$, $P < 0.001$, Fig. 4). PIF had positive relationship with COP velocity of flexion, extension, and bending to the affected and less affected side ($r = 0.352$-0.660, $P < 0.05$) and with COP path length of extension ($r = 0.683$, $P < 0.001$) (Table 6). In VC, there was positive relationship with COP path length of extension ($r = 0.498$, $P < 0.01$) (Table 6).

Discussion

The present study examined the TrA, IO, EO, and RA as forced expiratory muscles (Neumann 2010) and the diaphragm as an inspiratory muscle (Neumann 2010). A previous study compared the EO, IO and TrA contractility in 47 stroke patients with hemiparesis and 25 age-matched healthy control subjects using musculoskeletal ultrasonography (Kim et al. 2014). They reported that only contractility of TrA was significantly decreased in both side compared to control group. However, our results was different because the resting thickness of the TrA, IO, and EO showed a significant difference between the affected and less affected side. This suggests that the resting thickness of the TrA, IO, and EO may be decreased because of the longer duration since stroke onset (> 6 months), compared with that in patients (< 3 months) in the previous study (Kim et al. 2014). The TrA thickness on the affected side

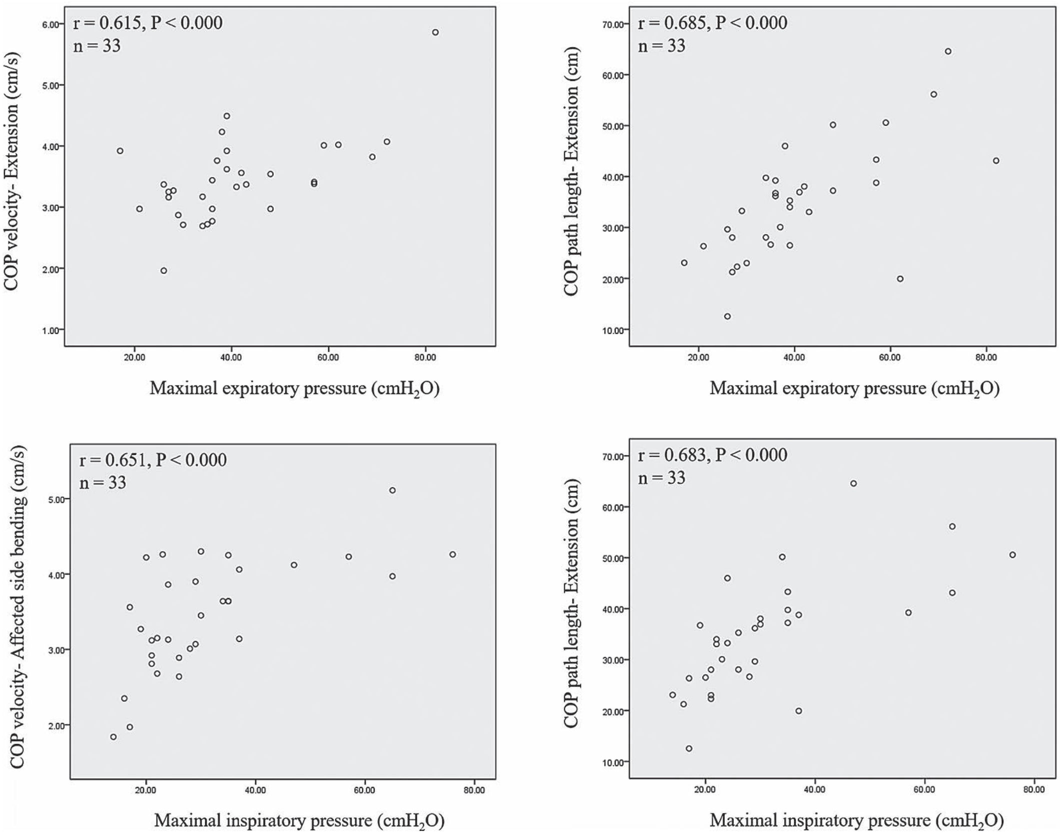

Fig. 4. Correlations between respiratory muscle function and trunk balance.
Maximum expiratory pressure was significantly correlated with trunk balance, especially COP velocity and COP path length in trunk extension. In addition, maximum inspiratory pressure demonstrated a significant correlation with COP velocity of the trunk on the affected side with regard to bending and COP path length in trunk extension.
COP, center of pressure.

Table 6. Correlations between respiratory muscle function and trunk balance (n = 33).

		COP velocity (cm/s)				COP path length (cmH$_2$O)			
		Flexion	Extension	ASB	LASB	Flexion	Extension	ASB	LASB
MEP	r	0.382	**0.615**	**0.561**	**0.472**	–0.176	**0.685**	**0.453**	0.307
	P-value	0.031	**0.000**	**0.001**	**0.006**	0.335	**0.000**	**0.009**	0.088
PEF	r	0.210	0.250	**0.447**	**0.452**	–0.152	**0.615**	0.077	–0.014
	P-value	0.248	0.167	**0.010**	**0.009**	0.407	**0.000**	0.675	0.940
FEV1	r	0.333	0.292	**0.522**	**0.574**	–0.267	**0.648**	0.201	0.103
	P-value	0.062	0.105	**0.002**	**0.001**	0.139	**0.000**	0.269	0.574
MIP	r	**0.363**	**0.410**	**0.651**	**0.522**	–0.131	**0.683**	0.372	0.183
	P-value	**0.041**	**0.020**	**0.000**	**0.002**	0.474	**0.000**	0.036	0.316
PIF	r	**0.352**	**0.401**	**0.660**	**0.529**	–0.129	**0.683**	0.374	0.183
	P-value	**0.048**	**0.023**	**0.00**	**0.002**	0.482	**0.000**	0.035	0.316
VC	r	0.269	0.116	0.320	0.328	–0.211	**0.498**	0.211	0.083
	P-value	0.136	0.527	0.074	0.067	0.247	**0.004**	0.247	0.650

COP, center of pressure; ASB, affected side bending; LASB, less affected side bending; MIP, maximum inspiratory pressure; PIF, peak inspiratory flow; VC, vital capacity; MEP, maximum expiratory pressure; PEF, peak expiratory flow; FEV1, forced expiratory volume in 1 s.
Values in bold are significant.

and the thickness of the diaphragm during contraction was less than that on the less affected side, but the thickening ratio of the abdominal muscles did not differ between sides, except for EO. This may be because the thickening ratio is not based on absolute thickness but instead on an increasing ratio. The change in abdominal muscle thickness on the affected side from rest to contraction was less than on the less affected side, although the ratio was not significantly different.

Trunk balance can be improved by the co-contraction of abdominal muscles that increase intra-abdominal pressure (IAP) (Willson et al. 2005; Nagrale et al. 2012; Martuscello et al. 2013). Functionally, these muscles also play a role in respiration. We hypothesized that thickness during contraction and the thickening ratio of these muscles would be positively related to trunk function. Our results showed that total TIS score was associated with the diaphragm thickening ratio of the affected and less affected side. However, the thickening ratio of the forced expiratory muscles was not associated with total TIS score. That is, postures are induced by diaphragmatic pressure and co-contraction of the anterior and lateral abdominal muscles; thus, muscle thickness can be a crucial element of trunk balance (Saeys et al. 2012; Haruyama et al. 2017). The coordination of their contraction and those of adjacent muscles of the abdominal cavity reconcile respiratory, abdominal, and trunk movement (Hodges and Gandevia 2000a). This coordination may be impaired in stroke patients, resulting in decreased trunk balance (Lanini et al. 2003).

The results of this study demonstrated a significant correlation between forced expiratory and inspiratory muscle function and total TIS score. This may be because the TrA, IO, and EO comprise the lower trunk via the abdominal aponeurosis, which encloses the long muscles located in the stomach area, from the bottom of the chest to the top of the pubic area, along with the RA. The diaphragm constitutes the roof of this structure, and the diaphragm and anterolateral abdomen are critical in trunk support and movement control (Key 2013). IAP is generated when the diaphragm descends, creating a simultaneous reflex co-activation of the TrA and the pelvic floor muscles (Hodges et al. 2001). The forced expiratory and inspiratory muscle function and total TIS score may be related because the co-contraction of abdominal muscles contributes to IAP, which is needed to maintain trunk balance (Saunders et al. 2004). These results suggest that stroke patients are likely to have some impairment in forced expiratory and inspiratory muscle function because of the weakening of the abdominal muscles. Thus, functional changes occur in the forced expiratory and inspiratory muscles when trunk balance is needed, and coordination of abdominal muscles activities is required (Hodges and Gandevia 2000b; Saunders et al. 2004).

Previous analysis has focused on spontaneous weight bearing (Au-Yeung 2003) and the limit of stability during voluntary trunk movement (Perennou et al. 1998). The area covered by COP excursion was considered an indicator of postural performance (Bohannon 1995; Perennou et al. 1998). While leg muscles may assist in trunk balance in the anteroposterior direction, lateral sitting balance almost completely depends on the trunk muscles (van Nes et al. 2008). Thus, this study used a table with an adjustable height to accurately assess the changes in ground reaction forces by not allowing patients to contact the ground with their feet. Stroke patients, who are characterized by enhanced COP velocity, would require increased activity to maintain a more unstable sitting posture (Genthon et al. 2007). The limit of stability, which is also defined as the maximal COP position that patients are able to maintain without falling, is reduced in the sitting posture (Nichols et al. 1996). The results of this study showed that COP velocity of bending to the affected and less affected side and COP path length of trunk extension showed a positive association with forced expiratory and inspiratory muscle function. The reason for this may be that forced expiratory and inspiratory muscle function, especially MEP, PEF, MIP, and PIF, result from the voluntary contraction of the abdominal and internal intercostal muscles, which also function as trunk stabilizers, together with the diaphragm and other axial muscles (Hodges and Gandevia 2000b). Thus, when trunk balance is required, functional changes occur in the forced expiratory and inspiratory muscles, especially in the TrA and diaphragm. Similar to previous study findings (Jandt et al. 2011), FEV1 and VC were not significantly correlated with trunk balance. This may be because these variables are associated with the condition of the lungs rather the structures responsible for this observed state. Thus, it is understandable that MEP, PEF, MIP, and PIF were revealed to be significantly correlated with trunk control. This finding may represent the indirect connection between this variable and the abdominal musculature.

A limitation of this study is the small number of participants. We believe that future studies with a larger sample size may provide a link between disease severities, forced expiratory and inspiratory muscle strength, and trunk balance, and can clarify the relationship between these parameters in stroke patients. Moreover, the forced expiratory muscle thickening ratio of the affected and less affected sides was not correlated with total TIS score, possibly due to the difference in testing positions. Forced expiratory and inspiratory muscle thicknesses were measured in the supine position, while TIS was evaluated in the sitting position. Forced expiratory and inspiratory muscle thicknesses can be reliably measured in the supine posture because muscle thickness can be measured under conditions less affected by gravity. However, TIS can be evaluated in the sitting posture. Another limitation to the study is the possible effect of learning during the evaluation of MIP and MEP because of a potential leak from the nozzle during evaluation in patients with stroke who had facial weakness and who may not have maintained a good oral seal.

Chronic stroke patients have thinner abdominal muscles on the affected side than on the unaffected side; this is particularly apparent in the TrA and diaphragm. Trunk function was correlated with respiratory muscle function, and respiratory muscle function was correlated with trunk balance. Muscles that play a role in trunk balance contribute to respiratory function, and can be used for indirect evaluation of trunk function and balance. Moreover, respiratory muscle function plays an important role in trunk function and balance in healthy subjects. In other words, it might be better to focus on new findings that may be specific to stroke patients. We believe that respiratory muscle training should be included as part of trunk balance training in chronic stroke patients.

Conflict of Interest

The authors declare no conflict of interest.

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