Progressive Respiratory Muscle Training for Improving Trunk Stability in Chronic Stroke Survivors: A Pilot Randomized Controlled Trial

Kyeongbong Lee, PT, PhD,* Daesung Park, PT, PhD,† and GyuChang Lee, PT, PhD‡

Background: Stroke weakens the respiratory muscles, which in turn may influence the trunk stability; it is unclear whether the progressive respiratory muscle training (RMT) is effective in improving the trunk stability. The aim of this study was to investigate the effects of progressive RMT with trunk stabilization exercise (TSE) on respiratory muscles thickness, respiratory muscle functions, and trunk stability in chronic stroke survivors. *Methods:* This is a pilot randomized controlled trial. Chronic stroke survivors (n = 33) who were able to sit independently participated in the tstudy. The participants were allocated into the RMP with TSE group or the TSE group. The respiratory muscle thickness during resting and contraction were measured. Maximal expiratory pressure (MEP), peak expiratory flow (PEF), and forceful expiratory volume at 1 sec (FEV1) for forced expiratory muscle function and maximal inspiratory pressure (MIP), peak inspiratory flow (PIF), and vital capacity (VC) for inspiratory muscle function were examined. Trunk stability was estimated by maximal velocity and path length of the center of pressure (COP) by using a balance board with sitting posture. *Results:* The respiratory muscle thickness was significantly increased on the affected side in the RMT group than in the TSE group. The MEP, PEF, MIP, and PIF were significantly increased in the RMT group than in the TSE group; however, FEV1 and VC showed no significant differences between the 2 groups. Trunk stability for the maximal velocity of COP of extension and affected side bending was significantly increased in the RMT group than in the TSE group. In addition, the maximal path length of COP of flexion, extension, affected/less affected side bending was significantly increased in the RMT group than in the TSE group. *Conclusions:* RMT combined with TSE can be suggested as an effective method to improve the respiratory muscle thickness, respiratory muscle functions, and trunk stability in chronic stroke survivors as opposed to TSE only.

Key Words: Stroke—respiratory muscle training—trunk stability—randomized controlled trial

Introduction

More than 80% of the first-time stroke patients have impaired stability,[1,2] which is associated with poor recovery of activities of daily living and mobility and an increased risk of falls.[3,4] Stroke patients show remarkable asymmetry of the trunk and pelvis, increased posture sway, decreased dynamic stability, and impaired weight-shifting ability onto the affected side when sitting and standing.[5,6] They also exhibit a significantly reduced level of trunk performance compared with healthy individuals.[7] Stroke reduces a patient's quality of life by impairing static/dynamic balance and the basic physical activity requirements.[8]

One of the effective techniques to improve trunk stability is the performance of trunk stabilization exercises

From the *Physical Therapy Part, Physical & Rehabilitation Medicine, Samsung Medical Center, Seoul, Republic of Korea; †Department of Physical Therapy, Konyang University, Daejeon, Republic of Korea; and ‡Department of Physical Therapy, Kyungnam University, Changwon, Republic of Korea.

Received August 7, 2018; revision received December 27, 2018; accepted January 12, 2019.

Address correspondence to GyuChang Lee, PT, Ph.D, Department of Physical Therapy, Kyungnam University, 7 Kyungnamdaehak-ro Masanhappo-gu, Changwon 51767, Republic of Korea. E-mail: leegc76@hanmail.net.

1052-3057/$ - see front matter

https://doi.org/10.1016/j.jstrokecerebrovasdis.2019.01.008

Table 1. *Participants' characteristics*

	RMTG (n = 13)	TSEG (n = 12)	$X^2/t(p)$
Gender			
Male/Female (%)	7/6 (53.8/46.2)	5/7 (41.6/58.4)	0.371 (0.695)
Stroke types			
Infarction/Hemorrhage (%)	6/7 (46.2/53.8)	6/6 (50.0/50.0)	0.037 (1.000)
Hemiplegic side			
Right/Left (%)	8/5 (61.5/38.5)	3/9 (25.0/75.0)	3.381 (0.111)
Disease duration (m)	11.15 (2.38)	11.00 (2.17)	0.168 (0.868)
Age (y)	58.62 (12.38)	59.75 (13.38)	−0.218 (0.829)
Height (cm)	163.13 (6.98)	165.20 (11.49)	−0.549 (0.588)
Weight (cm)	62.77 (9.43)	66.50 (11.68)	−0.822 (0.387)
MMSE (score)	28.08 (1.98)	27.25 (1.77)	1.100 (0.238)
Trunk impairment scale (score)			
Static	5.38 (1.26)	5.58 (0.67)	−0.486 (0.632)
Dynamic	4.92 (2.36)	5.00 (1.60)	−0.095 (0.925)
Coordination	1.08 (4.94)	1.08 (0.29)	−0.039 (0.969)
Total	11.38 (3.43)	11.67 (2.19)	−0.243 (0.810)

Values are expressed as mean (standard deviation) or mode (100 percentage).

Abbreviations: MMSE, mini mental status examination; RMTG, respiratory muscle training with trunk stabilization exercise group; TSEG, trunk stabilization exercise group.

(TSE), which involve voluntary cocontraction of the respiratory muscles.[9] From an anatomical view, both respiratory muscles play a dual role in breathing and trunk stability during exercise.[10] As respiratory (especially deep abdominal) muscles are part of the trunk musculature, they may influence trunk stability. Stroke survivors show a partial or total weakening of the respiratory muscles on the affected side.[10,11] About 40% of the stroke survivors show decreased diaphragm movement, decreased lung function by 50% of the age-expected values,[12] and a decreased maximal expiratory/inspiratory pressure compared with healthy individuals.[13] Thus, stroke weakens the respiratory muscles, which in turn may influence the trunk stability; however, it is unclear whether the progressive respiratory muscle training (RMT) is effective in improving the respiratory muscle functions and whether it affects trunk stability in chronic stroke survivors.

Therefore, the aim of this study is to investigate the effects of progressive RMT combined with TSE on respiratory muscle thickness, respiratory muscle functions, and trunk stability in chronic stroke survivors compared to TSE only. Our hypothesis is that progressive RMT along with TSEs are more effective in improving the variables than TSE only.

Methods

Design Overview

This is a pilot randomized controlled trial of 2 experimental group designs, involving survivors with hemiplegia/hemiparesis who had cerebral infarction/hemorrhage. They were grouped into 2: RMT combined with TSE group and TSE group. The baseline assessment was performed on the first day, and the final assessment was conducted after the 6-week intervention. After collection of general characteristics and anthropometric measurement of subjects' data (Table 1), the respiratory muscles thickness, respiratory muscle functions, and trunk stability were examined as the outcomes of the study.

Participants and Setting

The details of this study were announced on the bulletin board for 1 month in M rehabilitation hospital in Seoul, Republic of Korea, 33 chronic stroke survivors volunteered to be participants in the study from the hospital. Sample size was calculated by a previous study for post-stroke stability evaluation.[14] It was based on the independent *t* test, the mean difference of center of pressure (COP) velocity was used. The α-error probability was set at .05 and power was set at 80%. The sample size of 14 participants was chosen as an appropriate size for the pilot study. Inclusion criteria were as follows: (1) had experienced their first stroke, whether ischemic or hemorrhagic (not requiring surgery) over 6 months, (2) a Mini−Mental Status Examination score more than and equal to 24, (3) no facial palsy and receptive aphasia, (4) and no prior thoracic or abdominal surgery. Exclusion criteria were as follows: (1) use of medications for neuromuscular control or that provoke drowsiness, (2) significant disability prior to stroke as evidenced by a score of more than 3 on the Modified Rankin Scale[15] (3) evidence of restrictive lung disease based on lung volumes, (4) Trunk Impairment Scale[16] score less than 10, and (5) musculoskeletal problems in the pelvis or spine.[17] Volunteers were included if they had no RMT within 1 year.

Table 2. *Trunk stabilization exercise program during 6 wks*

	Stable support surface (mattress)	Unstable support surface (gym ball)
1st∼2nd wk	Supine: pelvic bridge, unilateral bridge Sitting: lower trunk flexion extension Upper trunk lateral flexion	Supine: pelvic bridge, unilateral bridge (gym ball) Sitting: lower trunk flexion extension Upper trunk lateral flexion(gym ball)
3rd∼4th wk	Supine: upper trunk flexion rotation, lower trunk flexion rotation Sitting: lower trunk lateral flexion, upper trunk rotation	Supine: upper trunk flexion rotation, lower trunk flexion rotation (gym ball) Sitting: lower trunk lateral flexion, upper trunk rotation (gym ball)
5th∼6th wk	Sitting: weight shifting, forward reach Lateral reach	Sitting: Weight shifting, forward reach Lateral reach (gym ball)

Randomizations

This study was a randomized controlled, assessor-blinded trial. When the physical therapists had obtained written informed consent from the participants, they had a box containing 33 sealed envelopes, 17 of which contained a green note (control group) and 16 with a yellow note (intervention group). The administrator, who did not know what the colors represented, picked a sealed envelope from the box and reported the color of the note to the therapists. Because of the nature of the intervention, there was no blinding of the stroke survivors or physical therapist following randomization.

Procedure

Because this study was conducted at a rehabilitation hospital, all patients received conventional physical and occupational therapy conducted for 30 minutes, 2 times a day, and 6 times per week, but no RMT or TSE. Progressive RMT included forced expiratory/inspiratory muscle training. Because there is resistance to normal respiration, participants of the RMT group may experience dizziness, light-headedness, or a headache and exhibit abnormal heart rate or oxygen saturation,[18,19] the sign screened Finger Pulse Oximeter (FDA approved).

To objectify the progressive RMT, the maximal expiratory pressure (MEP) and maximal inspiratory pressure (MIP) were assessed at the beginning of every week, 30% of the MEP (Micro RPM, Micro Medical, Kent, UK) and MIP (POWERbreathe K5, HaB International Ltd, UK) were set as the resistance intensity on the first day of the week. Thus, the progressive RMT in this study was one of the progressive resistance trainings. Commercially available handheld expiratory/inspiratory-type pressure threshold devices (Threshold PEP, Threshold IMT-Philips Respironics, Andover, MA) were used.[20]

RMT group participants were comfortably seated on a chair with their feet on the ground, without back support, and their trunk at a 90° angle to their hips. A conventional nose clip was used to prevent air leakage. In forced expiratory muscle training, the participants held the Threshold PEP with a personalized mouthpiece and performed forced expiration through the device to overcome the adjusted resistance. After maximal inspiration, the subject stopped breathing for about 2 seconds with the mouthpiece placed in his mouth and forced exhalation. The inspiratory muscle training was performed following the same procedure as the forced expiratory muscle training using the Threshold IMT. Both forced expiratory/inspiratory muscle training were repeated 10-15 times, 5 set for 20 minutes in a session and a resting time of 30-60 seconds between each set.

Both RMT group and TSE group were trained 40 minutes, 3 times a week for 6 weeks. The program of TSE consisted that the stage was proceeding every 2 weeks using both stable and unstable support surface (Table 2). The RMT group performed the TSE for 20 minutes, whereas the TSE group performed the exercise for 40 minutes for consistency of intervention duration (Fig 1). The number of repetitions and progression of TSE were determined based on the patient's ability by the physiotherapist in charge.[21]

Primary Outcome Measurements

Trunk stability

We aimed to compare the effect of progressive RMT on trunk stability in chronic stroke survivors between RMT group and TSE group, we assessed the trunk stability based on the maximal velocity and path length of center of pressure in limit of stability during trunk flexion, extension, and affected/less affected side bending in sitting position. We intended an easy approach to assessing the trunk stability in a clinical setting. We used a Nintendo Wii Balance Board (WBB) with a laptop-installed Balancia v2.0 software (Minto systems, Seoul, Republic of Korea) and built-in Bluetooth (The interrater reliability, ICC: .89-.79; intrarater reliability, ICC: .92-.70; concurrent validity, ICC: .87-.73).[22] The WBB was placed on a wooden floor table with an adjustable height to avoid the subjects' feet from touching the ground, and both arms were crossed and placed in front of the chest.[17] The subject's sacrum was positioned 1 cm inward from the rear side of the WBB to ensure the consistency of the experimental procedure. It was

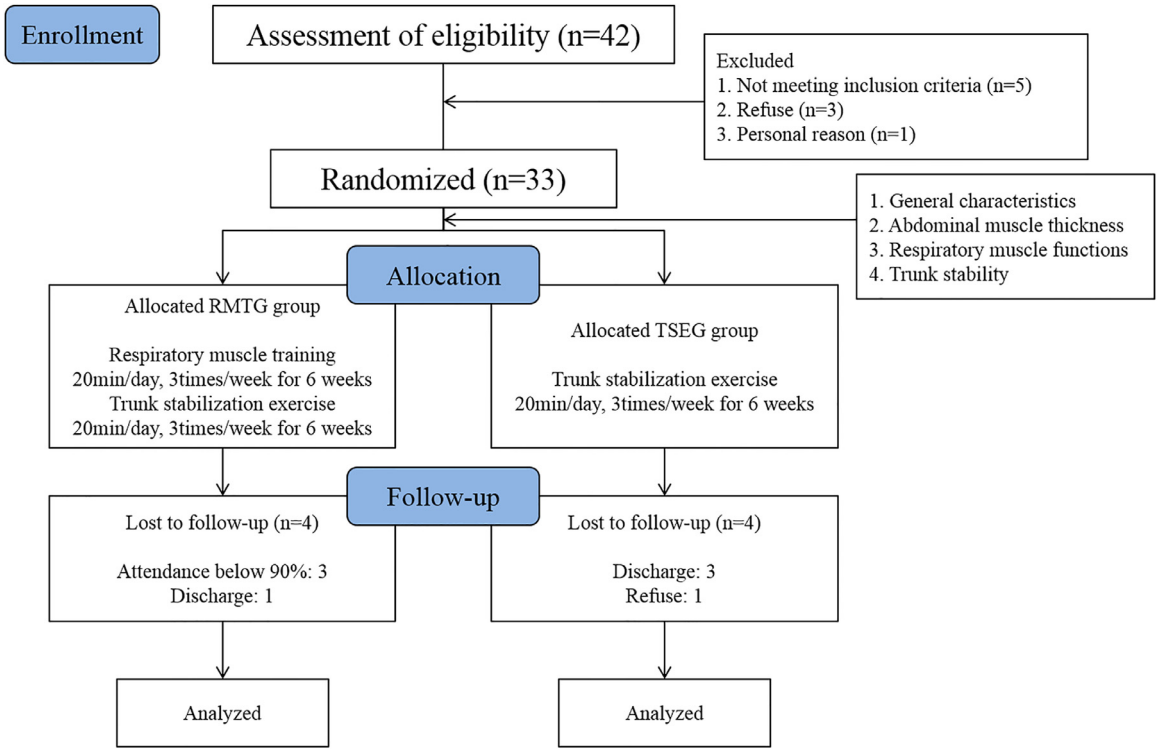

Figure 1. *Flow chart of experimental procedure. Abbriviations: RMTG, respiratory muscle training with trunk stabilization exercise; TSEG, trunk stabilization exercise group. (Color version of figure is available online.)*

required the subject's sacrum to be positioned anywhere of the WBB, the position is defined as the automatically starting point by a laptop with the software installed, therefore there was no need to try and match the starting point for all participants. To reduce the subject's anxiety during the measurement process, practices were provided to give feedforward. Then, the examiner gave verbal instructions to tilt their trunk as far and as fast as possible to the given directions within their limit of stability. After tilting the head and trunk to the maximum point, the result of the maximal COP velocity and COP path length is automatically calculated through the software. All procedures were randomly conducted and enough break time between each trial was given to minimize the fatigue of subjects and all tests were performed before and after the intervention.

Secondary Outcomes Measurements

Respiratory muscle functions

To examine the effects of progressive RMT and TSE, the present study assessed the respiratory forced expiratory/inspiratory muscle functions.[23] To evaluate forced expiratory muscle functions, MEP was measured using Micro RPM and peak expiratory flow (PEF) and forceful expiratory volume in 1 second (FEV1) was measured using a Microlife PF 100 Peak Flow Meter.[19] The subject kept the trunk and hip joint at 90° in sitting position with feet on the ground without a backrest. With the use of a conventional nose clip to prevent air leakage, each participant performed maximal inspiration and expelled the air as fast as possible; however, there was no visual feedback such as excessive chest expansion and minimized compensatory movement. After 2 practices without using the device, the highest value was selected after 3 trials, and the resting period was set to 5 minutes or higher according to the subjects' request.[24] Data were collected as the value when no air leakage was noted in the mouthpiece and can be maintained for at least i second or a difference of less than 10% of the maximum value occurs. The measurement bias was minimized by allowing a resting time of at least 10 minutes between trials, and the result was calculated at the highest value.[25]

Inspiratory muscle functions were measured for MIP, PIF, and VC (POWERbreathe K5, HaB International Ltd, UK), which are automatically calculated in a single resisted inspiration.[26] The subject's posture remained the same as for the forced expiratory muscle function test. The functions were evaluated using J-Lab software version 5.22.1.50 (Cardinal Health GmbH, Hoechberg, Germany).

Respiratory muscles thickness

One of the factors that directly affect trunk stability is the ability of the core muscles to contract; these muscles have a direct effect on forced expiration and inspiration.

In this study, we measured the thickness of the transverse abdominis (TrA), rectus abdominis (RA), and diaphragm, which represent core and respiratory muscles. The affected/less affected side of the respiratory muscles thickness during resting and contraction was measured using ultrasonography before and after the intervention. A linear transducer of a B-mode 7.5 MHz ultrasound device (Mysono U5, Samsung Medison, Seoul, Korea)

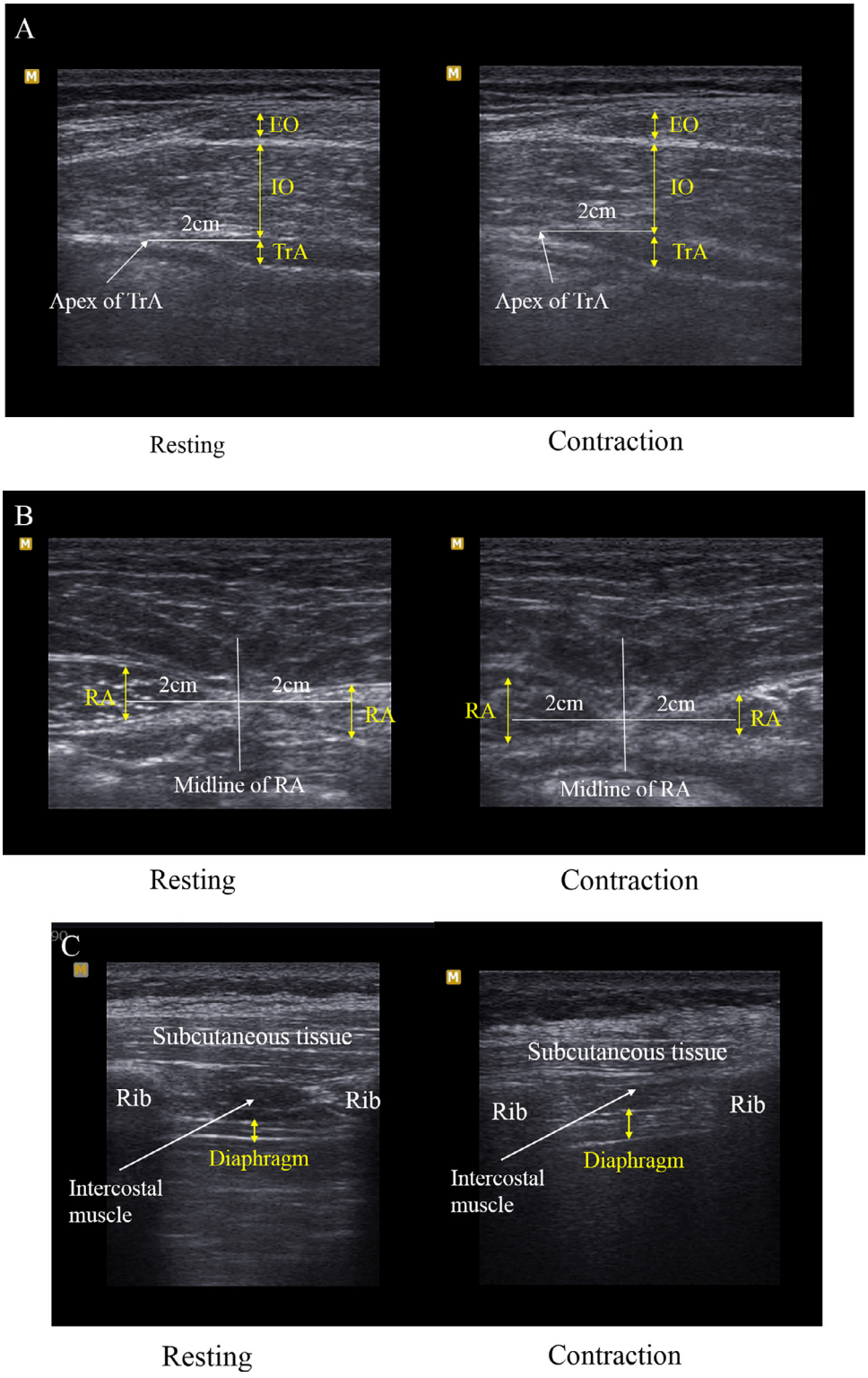

Figure 2. *Resting and contraction thickness of transverse abdominis (A), rectus abdominis (B), and diaphragm of the chronic stroke survivors. (Color version of figure is available online.)*

was used and the modulation frequency range was 6-8 MHz according to the patient's waist circumference.

For consistency of ultrasound imaging of the TrA and RA, the forced expiratory muscles, the patient was in the crooked lying position, with a pillow behind the head and knees to minimize tension of the lumbar spine and abdomen (.95-1.00 for intraimage reliability; .77-.97 for interimage reliability).[27] To obtain clear images, the transducer was placed transversely on the abdominal wall of the anterior axillary line and between the 12th rib and iliac crest.[28] This provides a reference point for the ultrasound images of the TrA muscle. Thickness measurements were taken from the outer border of the hyperechoic fascia line of each muscle (Fig 2, A). The ultrasound image of the RA muscle can be obtained by locating the center of the transducer on a vertical line along the navel and placing the transducer transversely to the position 2-3 cm superiorly from the navel (test-retest reliability: .89-.96).[28] Ultrasound images were obtained at end of expiration for the resting thickness (Fig 2, B) and at end of the forced expiration for the contraction thickness.[27]

To obtain ultrasound images of the diaphragm, an inspiratory muscle, a transducer was placed vertically at the point at which the anterior axillary line meets just at the superior area of the lower intercostal angle (inter-rater reliability, .97∼.98; intrarater reliability were .94∼.98).[29] At this location, the hypoechoic and hyperechoic layers of the soft tissue (pleura and peritoneum) between the 2 ribs can be identified, and the distance between the 2 layers was defined as diaphragm thickness (Fig 2, C). Diaphragm images for the resting thickness were taken at the end of expiration and those for contraction thickness were obtained at the end of maximal inspiration.[29]

Statistical Analysis

PASW statistics 18.0 (SPSS) was used to analyze the data. The general characteristics and normal distribution were identified by the Kolmogorov−Smirnov test; all variables satisfied the normal distribution. Homogeneity test was used for categorical variables using the chi-square test while continuous variables were examined by the independent t test. To compare the differences within each RMT group and TSE group, a paired t test was conducted; the independent t test was used to compare the differences between RMT group and TSE group. Results were considered significant at a P value of less than .05.

Results

The results comparing the respiratory muscle thickness during resting and contraction of the affected and less affected sides before and after intervention are shown in Table 3. The resting thickness of TrA, RA, and diaphragm of the affected and less affected side of RMT group was significantly increased ($P < .05$). In TSE group, only TrA of the affected side was significantly increased ($P < .01$). The contraction thickness of TrA, RA, and diaphragm's affected and the less affected side was significantly increased both in the RMT group and TSE group within each group ($P < .01$). Between group comparisons, the resting thickness of the diaphragm of less affected side was significantly increased in the RMT group ($P < .01$). In contraction, thickness TrA and diaphragm were significantly increased in the RMT group ($P < .05$), however, no significant increase was present in the less affected side of respiratory muscles.

The results comparing the respiratory muscle functions between the RMT group and TSE group before and after intervention are described in Table 4. The MEP, PEF, FEV1, MIP, PIF, and VC were significantly increased within both groups ($P < .05$). Between-group comparison, MEP, PEF, MIP, and PIF were significantly increased in the RMT group compared with the TSE group ($P < .05$).

Table 5 demonstrates the results of trunk stability difference before and after the intervention. The maximal COP velocity in limit of stability during trunk flexion, extension, and affected/less affected side bending the in sitting position was significantly increased within each RMT group ($P < .05$; $P < .001$; $P < .01$; $P < 0.05$, respectively) and TSE group ($P < .001$, $P < .001$, $P < .01$, $P < .001$, respectively). Between groups, the maximal COP velocity in the limit of stability during trunk extension and affected side bending was significantly increased in the RMT group than in TSE group ($P < .05$; $P < .05$, respectively). The maximal COP path length in each group was significantly increased during trunk flexion, extension, and affected/less affected side bending were significantly increased in both RMT group ($P < .001$) and TSE group ($P < .01$) each. Between groups, the maximal COP path length in the limit of stability during trunk flexion, extension, and affected/less affected side bending ($P < .05$) was significantly increased in RMT group than in TSE group (Table 6).

Discussion

Forced expiration at the end of the tidal volume can induce actual contraction of the TrA.[30,31] During inspiration, the diaphragm contracts and moves to an inferior direction, creating an abdominal pressure in the trunk. We intended to confirm the progressive resistance training effects of the respiratory muscles by adding the progressive resistance to forced expiration and inspiration. However, it is unknown whether voluntary cocontraction of respiratory muscles through forced expiration/inspiration with resistance is an effective TSE. Thus, in the present study, progressive RMT was carried out to train the TrA, RA, and diaphragm automatically through resistance on forced expiration and inspiration which have the functions of trunk stabilizing muscles. The results of this study, for both the RMT group and TSE group, demonstrated thickness changes which significantly increased in

Table 3. *Comparison of resting and contraction thickness of respiratory muscles in affected and less affected side*

			Resting thickness of deep abdominal muscles			Contraction thickness of deep abdominal muscles		
			RMTG (n = 13)	TSEG (n = 12)	t(p)	RMTG (n = 13)	TSEG (n = 12)	t(p)
Affected side	TrA (cm)	Pretest	0.20 (0.07)	0.17 (0.04)		0.27 (0.09)	0.24 (0.05)	
		Posttest	0.24 (0.07)	0.20 (0.05)		0.37 (0.09)	0.31 (0.08)	
		Changes	0.05 (0.04)	0.03 (0.03)	1.073 (0.294)	0.11 (0.07)	0.06 (0.05)	**1.806 (0.035)**
		t(*p*)	**3.776 (0.003)**	**3.593 (0.004)**		**5.546 (0.000)**	**4.252 (0.001)**	
	RA (cm)	Pretest	0.57 (0.19)	0.60 (0.17)		0.67 (0.16)	0.68 (0.20)	
		Posttest	0.71 (0.14)	0.63 (0.18)		0.83 (0.10)	0.77 (0.20)	
		Changes	0.13 (0.20)	0.03 (0.12)	1.621 (0.119)	0.16 (0.17)	0.09 (0.06)	1.369 (0.191)
		t(*p*)	**2.434 (0.031)**	0.767 (0.459)		**3.276 (0.007)**	**5.466 (0.000)**	
	Diaphragm (cm)	Pretest	0.23 (0.06)	0.24 (0.09)		0.42 (0.14)	0.43 (0.16)	
		Posttest	0.30 (0.08)	0.30 (0.14)		0.77 (0.21)	0.66 (0.16)	
		Changes	0.07 (0.07)	0.06 (0.10)	0.442 (0.662)	0.35 (0.17)	0.23 (0.16)	**1.857 (0.023)**
		t(*p*)	**3.599 (0.004)**	1.940 (0.078)		**7.555 (0.000)**	**5.100 (0.000)**	
Less affected side	TrA (cm)	Pretest	0.20 (0.04)	0.21 (0.06)		0.29 (0.06)	0.29 (0.07)	
		Posttest	0.26 (0.07)	0.25 (0.06)		0.39 (0.09)	0.36 (0.09)	
		Changes	0.06 (0.06)	0.05 (0.05)	0.588 (0.562)	0.10 (0.08)	0.08 (0.10)	0.692 (0.496)
		t(*p*)	**3.614 (0.004)**	**2.912 (0.014)**		**4.694 (0.001)**	**2.698 (0.021)**	
	RA (cm)	Pretest	0.59 (0.19)	0.52 (0.18)		0.74 (0.16)	0.61 (0.17)	
		Posttest	0.74 (0.12)	0.63 (0.19)		0.87 (0.13)	0.78 (0.17)	
		Changes	0.15 (0.05)	0.12 (0.12)	0.596 (0.557)	0.13 (0.12)	0.18 (0.18)	0.827 (0.417)
		t(*p*)	**3.633 (0.003)**	**3.336 (0.007)**		**3.794 (0.003)**	**3.330 (0.007)**	
	Diaphragm (cm)	Pretest	0.23 (0.06)	0.26 (0.07)		0.39 (0.16)	0.48 (0.17)	
		Posttest	0.32 (0.06)	0.29 (0.09)		0.76 (0.19)	0.71 (0.16)	
		Changes	0.10 (0.05)	0.04 (0.05)	**3.024 (0.006)**	0.36 (0.24)	0.23 (0.19)	1.499 (0.147)
		t(*p*)	**6.717 (0.000)**	**2.549 (0.027)**		**5.377 (0.000)**	**4.270 (0.001)**	

Values are expressed as mean (standard deviation).

Abbreviations: RMTG, respiratory muscle training with trunk stabilization exercise group; TSEG, trunk stabilization exercise group; TrA, transverse abdominis; RA, rectus abdominis.

Table 4. *Comparison of respiratory muscle functions between RMTG and TSEG*

		RMTG (n = 13)	TSEG (n = 12)	*t*(*p*)
MEP (cmH_2O)	Pretest	45.46 (16.02)	40.75 (16.01)	
	Posttest	67.31 (22.98)	51.92 (22.73)	
	Changes	12.85 (10.92)	11.17 (9.82)	**2.563 (0.017)**
	t(*p*)	**7.216 (0.000)**	**3.937 (0.002)**	
PEF (l/s)	Pretest	3.43 (1.39)	3.39 (1.54)	
	Posttest	4.93 (2.21)	3.87 (1.65)	
	Changes	1.50 (1.60)	0.48 (0.41)	**2.235 (0.043)**
	t(*p*)	**3.384 (0.005)**	**4.042 (0.002)**	
FEV1 (l)	Pretest	2.14 (0.66)	2.18 (1.01)	
	Posttest	2.57 (0.60)	2.55 (1.01)	
	Changes	0.43 (0.49)	0.37 (0.31)	2.235 (0.703)
	t(*p*)	**3.177 (0.008)**	**4.041 (0.002)**	
MIP (cmH_2O)	Pretest	30.48 (13.15)	36.42 (19.60)	
	Posttest	44.15 (14.49)	42.50 (19.43)	
	Changes	13.77 (6.43)	6.80 (7.00)	**2.862 (0.009)**
	t(*p*)	**7.720 (0.000)**	**3.001 (0.012)**	
PIF (l/s)	Pretest	1.67 (0.81)	2.04 (1.21)	
	Posttest	2.50 (0.84)	2.41 (1.05)	
	Changes	0.83 (0.46)	0.37 (0.37)	**2.734 (0.012)**
	t(*p*)	**6.527 (0.000)**	**3.323 (0.007)**	
VC (l)	Pretest	1.82 (0.67)	2.00 (1.03)	
	Posttest	2.28 (00.70)	2.28 (1.10)	
	Changes	0.46 (0.68)	0.28 (0.36)	0.809 (0.427)
	t(*p*)	**2.442 (0.031)**	**2.754 (0.019)**	

Values are expressed as mean (standard deviation).

Abbreviations: FEV1, forced expiratory volume in 1 second; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; PEF, peak expiratory flow; PIF, peak inspiratory flow; RMTG, respiratory muscle training with trunk stabilization exercise group; TSEG, trunk stabilization exercise group; VC, vital capacity.

Table 5. *Comparison of trunk stability for maximal velocity of center of pressure in limit of stability between RMTG and TSEG*

		RMTG (*n* = 13)	TSEG (*n* = 12)	*t*(*p*)
Flexion (cm/s)	Pretest	3.58 (0.64)	3.53 (0.49)	
	Posttest	4.75 (1.70)	3.90 (0.48)	
	Post-pre	1.25 (1.53)	0.36 (0.24)	1.984 (0.059)
	t(*p*)	**2.948 (0.012)**	**5.264 (0.000)**	
Extension (cm/s)	Pretest	3.78 (0.78)	3.34 (0.53)	
	Posttest	4.73 (0.84)	3.79 (0.61)	
	Post-pre	1.01 (0.22)	0.45 (0.28)	**2.624 (0.019)**
	t(*p*)	**4.777 (0.000)**	**5.548 (0.000)**	
Affected side bending (cm/s)	Pretest	3.46 (0.63)	3.72 (0.85)	
	Posttest	4.99 (1.74)	4.22 (0.97)	
	Post-pre	1.57 (1.38)	0.50 (0.38)	**2.695 (0.017)**
	t(*p*)	**4.118 (0.001)**	**4.599 (0.001)**	
Less affected side bending (cm/s)	Pretest	4.00 (0.86)	4.09 (1.02)	
	Posttest	5.68 (2.49)	4.63 (0.95)	
	Post-pre	1.73 (2.30)	0.59 (0.32)	1.764 (0.102)
	t(*p*)	**2.705 (0.019)**	**6.295 (0.000)**	

Values are expressed as mean (standard deviation).

Abbreviations: RMTG, respiratory muscle training with trunk stabilization exercise group; TSEG, trunk stabilization exercise group.

Table 6. *Comparison of trunk stability for maximal path length of center of pressure between RMTG and TSEG*

		RMTG (n = 13)	TSEG (n = 12)	*t*(*p*)
Flexion (cm)	Pretest	38.05 (14.71)	44.95 (23.20)	
	Posttest	50.77 (15.97)	50.59 (22.29)	
	Post-pre	16.55 (10.46)	7.37 (5.24)	**2.804 (0.012)**
	t(*p*)	**5.701 (0.000)**	**4.873 (0.000)**	
Extension (cm)	Pretest	37.82 (10.46)	35.15 (12.23)	
	Posttest	49.98 (12.99)	39.75 (12.95)	
	Post-pre	13.11 (5.20)	3.42 (6.25)	**3.953 (0.001)**
	t(*p*)	**4.734 (0.000)**	**7.182 (0.000)**	
Affected side bending (cm)	Pretest	33.94 (12.84)	32.76 (13.72)	
	Posttest	44.74 (15.97)	37.03 (13.67)	
	Post-pre	12.07 (9.19)	4.72 (2.27)	**2.692 (0.016)**
	t(*p*)	**4.734 (0.000)**	**7.182 (0.000)**	
Less affected side bending (cm)	Pretest	41.89 (18.50)	41.61 (22.64)	
	Posttest	53.05 (19.61)	46.97 (21.78)	
	Post-pre	12.61 (5.37)	4.78 (6.86)	**2.378 (0.026)**
	t(*p*)	**8.471 (0.000)**	**3.421 (0.006)**	

Values are expressed as mean (standard deviation).
Abbreviations: RMTG, respiratory muscle training with trunk stabilization exercise group; TSEG, trunk stabilization exercise group.

each group. Especially, the resting thickness of the diaphragm and contraction thickness of TrA and diaphragm of the RMT group were significantly increased compared to the TSE group. The muscle strength is highly correlated to muscle volume which is reflected by muscle thickness and cross-sectional area, these results can imply that RMT is more effective on increasing the respiratory muscle thickness than TSE. The findings of this study, an increasing muscle thickness in resting and contraction, cannot fully confirm that the respiratory muscle strength is improved by RMT, but implies the potential of muscle training on the actual contraction of TrA and diaphragm (for TSE). In addition, RMT may improve the muscle thickness of trunk stabilizing muscles by resistance on forced expiration and inspiration.

Contraction of the TrA muscle, which is located transversely around the spine, plays an important role in trunk stability.[32] TrA contraction increases the intra-abdominal pressure, which affects the correct alignment of the spine when external forces are applied to the trunk, and the thoracolumbar fascia disperses the external force applied to the trunk. Also, the diaphragm exists in a spatially appropriate position as the muscles that support the lower lumbar region and the pelvis from above.[33]

In this study, both groups showed a significant increase of respiratory muscle function within each group, and the MEP, PEF, MIP, and PIF were significantly increased in the RMT group compared to the TSE group. It may be an obvious result that the respiratory muscle functions improved due to progressive RMT. However, MEP and PEF are mainly produced by increasing intra-abdominal pressure induced by abdominal muscles contraction, such as TrA and RA. Also, MIP and PIF by diaphragm contraction either. Thus, it can be thought that the respiratory muscle functions, not expressed by the amount of air but by the maximum strength of the respiratory muscles, are improved as the contraction thickness increases. Aforementioned functions demonstrated significant improvement in RMT group. However, FEV1 and VC, have meaning the amount of air, did not show any significant difference between groups.

A previous study investigated the relationship between trunk function and respiratory function in stroke survivors,[34] and a meaningful relationship between trunk functions, MEP, and PEF was revealed. One of the possible reasons is that stroke survivors have lowered MEP and MIP because the respiratory muscles wrap the lower trunk and increase the intra-abdominal pressure; the weakened respiratory muscles can affect the respiratory muscle functions.[35] This coordination may be impaired in stroke survivors, resulting in asymmetric movements of the trunk and lesser respiration on the hemiplegic side.[13] In stroke survivors, the rib cage movement is decreased, which affects the tidal volume and signifies a chronic weakening of the respiratory muscles.[35] Thus, we believe the improvement of abdominal muscles contraction thickness is related to respiratory muscle functions, as they can affect the trunk stability by the ability to contract and make the intra-abdominal pressure.

Jandt et al investigated the correlation between trunk control, respiratory muscle strength, and pulmonary function in stroke survivors.[34] Trunk control was assessed through the Trunk Impairment Scale, and the respiratory muscle strength was assessed by manovacuometry. A relationship was found in the Trunk Impairment Scale, MEP, and PEF but no correlation was found between TIS and pulmonary functions. We also found a similar result that the RMT group showed a significant increase in the respiratory

muscle functions, not pulmonary function which can be represented by air volume. Further studies are required to obtain positive effects on the pulmonary function in stroke survivors who have symptoms of restrictive lung disease due to hemiplegia or hemiparesis.[36]

A training frequency of 1-2 times per day for 30 minutes performed in 3-5 days per week for 6 weeks has been suggested to induce desired changes.[37] We believe that the frequency and duration are represented by minimum exercise intensity to improve the abdominal muscle contraction thickness and respiratory muscle functions and suggest that a further study is needed to assess the ideal intensity and duration of training.

One of the contributing factors of trunk stability is diaphragmatic pressure and cocontraction of the anterior and lateral abdominal muscles, especially the TrA and diaphragm,[38] dysfunction and weakness of these muscles may affect the trunk stability and normal breathing. Even though expiration is a passive process, stroke survivors cannot perform it efficiently, as the forced expiratory muscles present a remarkable decrease in muscle activity.[39] One of the possible reasons is the location of the respiratory muscles at the center of the abdominal region and wrap of the lower trunk; the affected side of the respiratory muscles depends on effective muscle activation. In a more recent study, an investigation was conducted on the respiratory muscle strength of individuals with chronic stroke and found that stroke survivors have significantly lower MIP and MEP values than healthy individuals and weakness in the respiratory muscles which affects the trunk stability.[35] Hence, the diaphragm is activated whenever the trunk stability is disturbed coordination is required of its contraction and those of the adjacent muscles of the abdominal region, an integration of the respiratory muscles and trunk movements.[40]

We aimed to strengthen the respiratory muscles to improve trunk stability in chronic stroke survivors, especially the TrA and diaphragm by automatically contracting them by resistance to expiration and inspiration. Regarding trunk stability, RMT group showed a significant increase both in the maximal COP velocity during trunk extension and affected side bending and the maximal COP path length during trunk flexion, extension, and affected/less affected side bending compared with TSE group. The trunk musculature is responsible for maintaining the stability of the spine and pelvis.[41] TrA is the first activated muscle during lower limb movement following contralateral weight shifting,[42] whereas the diaphragm is the muscle that supports the lower lumbar region and pelvis[33]; stroke survivors with RMT demonstrated more developed trunk stability by progressive strengthening of the respiratory muscles induced by forced expiratory/inspiratory muscle training, even though not all of the forced expiratory/inspiratory muscle thickness was improved.

The first limitation of this study is the small number of participants. A previous study reported that trunk muscle thickening ratio and trunk function was significantly correlated, and trunk functions also have meaningful relationship with trunk stability for COP velocity and path length.[43] We believe that future studies with a larger sample size may provide a link between progressive RMT and trunk stability, and can clarify the relationship between these parameters in stroke survivors. Second, the position of the participant upon measurement of the respiratory muscle thickness using ultrasonography was different with respiratory muscle functions and Trunk Impairment Scale evaluation. In the supine position, the respiratory muscles thickness can be measured without difficulty, but the forced expiratory/inspiratory pressure can be influenced by position. Because of this, the respiratory muscle functions were evaluated in the sitting posture. However, we decided to use this sitting technique because we wanted to test the relationships of measurements performed under different conditions. Third, there is a bias for TSE program of weekly proceeding sequence that can be made by different evaluations of the physiotherapist-in-charge. Fourth, the effect of learning during the evaluation of respiratory muscle function can result in bias between RMT group and TSE group. Fifth, there is a possibility of leakage from the nozzle during evaluation in survivors of stroke who had facial weakness and who may not have maintained a good oral seal.

Conclusion

The results of this study demonstrated that the resting thickness of the TrA and diaphragm of stroke survivors increased in the RMT group. The respiratory muscle functions in terms of the MEP, PEF, MIP, and PIF confirmed that TSE combined with RMT yielded significant improvement compared with TSE only. In addition, the trunk stability measured by the maximal velocity and path length of the COP from the sitting position, COP velocity in extension and hemi-side bending and COP path length in flexion, extension, hemi-side, and sound-side bending were significantly increased after the intervention in RMT group than TSE group. Therefore, RMT can be suggested as an effective method to improve respiratory muscle contraction, respiratory muscle functions, and trunk stability in stroke survivors, compared with TSE alone.

References

1. Barker PJ, Guggenheimer KT, Grkovic I, et al. Effects of tensioning the lumbar fasciae on segmental stiffness during flexion and extension: Young Investigator Award winner. Spine 2006;31:397-405.
2. Tyson SF, Hanley M, Chillala J, et al. Balance disability after stroke. Phys Ther 2006;86:30-38.
3. Kwakkel G, Wagenaar RC, Kollen BJ, et al. Predicting disability in stroke—a critical review of the literature. Age Ageing 1996;25:479-489.

4. Lamb SE, Ferrucci L, Volapto S, et al. Risk factors for falling in home-dwelling older women with stroke: the Women's Health and Aging Study. Stroke 2003;34:494-501.
5. 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.
6. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing 2006;35(Suppl 2):ii7-ii11.
7. Verheyden G, Nieuwboer A, Feys H, et al. Discriminant ability of the Trunk Impairment Scale: a comparison between stroke patients and healthy individuals. Disabil Rehabil 2005;27:1023-1028.
8. Isho T, Usuda S. Association of trunk control with mobility performance and accelerometry-based gait characteristics in hemiparetic patients with subacute stroke. Gait Posture 2016;44:89-93.
9. Tayashiki K, Maeo S, Usui S, et al. Effect of abdominal bracing training on strength and power of trunk and lower limb muscles. Eur J Appl Physiol 2016;116:1703-1713.
10. Kawabata M, Shima N, Nishizono H. Regular change in spontaneous preparative behaviour on intra-abdominal pressure and breathing during dynamic lifting. Eur J Appl Physiol 2014;114:2233-2239.
11. Similowski T, Catala M, Rancurel G, et al. Impairment of central motor conduction to the diaphragm in stroke. Am J Respir Crit Care Med 1996;154:436-441.
12. Macko RF, Smith GV, Dobrovolny CL, et al. Treadmill training improves fitness reserve in chronic stroke patients. Arch Phys Med Rehabil 2001;82:879-884.
13. Lanini B, Bianchi R, Romagnoli I, et al. Chest wall kinematics in patients with hemiplegia. Am J Respir Crit Care Med 2003;168:109-113.
14. Bower KJ, Clark RA, McGinley JL, et al. Clinical feasibility of the Nintendo Wii for balance training post-stroke: a phase II randomized controlled trial in an inpatient setting. Clin Rehabil 2014;28:912-923.
15. Hong KS, Saver JL. Quantifying the value of stroke disability outcomes: WHO global burden of disease project disability weights for each level of the modified rankin scale. Stroke 2009;40:3828-3833.
16. Cabanas-Valdes R, Bagur-Calafat C, Girabent-Farres M, et al. The effect of additional core stability exercises on improving dynamic sitting balance and trunk control for subacute stroke patients: a randomized controlled trial. Clin Rehabil 2016;30:1024-1033.
17. Preuss RA, Popovic MR. Quantitative analysis of the limits of stability in sitting. J Appl Biomech 2010;26:265-272.
18. Jones HN, Crisp KD, Robey RR, et al. Respiratory muscle training (RMT) in late-onset Pompe disease (LOPD): effects of training and detraining. Mol Genet Metab 2016;117:120-128.
19. Messaggi-Sartor M, Guillen-Sola A, Depolo M, et al. Inspiratory and expiratory muscle training in subacute stroke: a randomized clinical trial. Neurology 2015;85:564-572.
20. Yeldan I, Gurses HN, Yuksel H. Comparison study of chest physiotherapy home training programmes on respiratory functions in patients with muscular dystrophy. Clin Rehabil 2008;22:741-748.
21. Yu SH, Park SD. The effects of core stability strength exercise on muscle activity and trunk impairment scale in stroke patients. J Exerc Rehabil 2013;9:362-367.
22. Park DS, Lee G. Validity and reliability of balance assessment software using the Nintendo Wii balance board: usability and validation. J Neuroeng Rehabil 2014;11:99.
23. Vincken W, Ghezzo H, Cosio MG. Maximal static respiratory pressures in adults: normal values and their relationship to determinants of respiratory function. Bull Eur Physiopathol Respir 1987;23:435-439.
24. Xiao Y, Luo M, Wang J, et al. Inspiratory muscle training for the recovery of function after stroke. Cochrane Database Syst Rev 2012. CD009360.
25. Neder JA, Andreoni S, Lerario MC, et al. Reference values for lung function tests. II. Maximal respiratory pressures and voluntary ventilation. Braz J Med Biol Res 1999;32:719-727.
26. Lee KB, Kim MK, Jeong JR, et al. Reliability of an electronic inspiratory loading device for assessing pulmonary function in post-stroke patients. Med Sci Monit 2016;22:191-196.
27. Stetts DM, Freund JE, Allison SC, et al. A rehabilitative ultrasound imaging investigation of lateral abdominal muscle thickness in healthy aging adults. J Geriatr Phys Ther 2009;32:60-66.
28. Tahan N, Khademi-Kalantari K, Mohseni-Bandpei MA, et al. Measurement of superficial and deep abdominal muscle thickness: an ultrasonography study. J Physiol Anthropol 2016;35:17.
29. Harper CJ, Shahgholi L, Cieslak K, et al. Variability in diaphragm motion during normal breathing, assessed with B-mode ultrasound. J Orthop Sports Phys Ther 2013;43:927-931.
30. Ishida H, Watanabe S. Changes in lateral abdominal muscles' thickness immediately after the abdominal drawing-in maneuver and maximum expiration. J Bodyw Mov Ther 2013;17:254-258.
31. Neumann DA. Kinesiology of Musculoskeletal System. 2nd ed. Elsevier Inc; 2010.
32. Arjmand N, Shirazi-Adl A, Parnianpour M. Relative efficiency of abdominal muscles in spine stability. Comput Methods Biomech Biomed Eng 2008;11:291-299.
33. Key J. 'The core': understanding it, and retraining its dysfunction. J Bodyw Mov Ther 2013;17:541-559.
34. Jandt SR, Caballero RM, Junior LA, et al. Correlation between trunk control, respiratory muscle strength and spirometry in patients with stroke: an observational study. Physiother Res Int 2011;16:218-224.
35. Teixeira-Salmela LF, Parreira VF, Britto RR, et al. Respiratory pressures and thoracoabdominal motion in community-dwelling chronic stroke survivors. Arch Phys Med Rehabil 2005;86:1974-1978.
36. Liaw MY, Wang LY, Pong YP, et al. Preliminary investigation of cardiopulmonary function in stroke patients with stable heart failure and exertional dyspnea. Medicine (Baltimore) 2016;95:e5071.
37. Crisafulli E, Costi S, Fabbri LM, et al. Respiratory muscles training in COPD patients. Int J Chron Obstruct Pulmon Dis 2007;2:19-25.
38. Hodges PW, Cresswell AG, Daggfeldt K, et al. In vivo measurement of the effect of intra-abdominal pressure on the human spine. J Biomech 2001;34:347-353.
39. Gosselink R, Kovacs L, Ketelaer P, et al. Respiratory muscle weakness and respiratory muscle training in severely

disabled multiple sclerosis patients. Arch Phys Med Rehabil 2000;81:747-751.
40. Hodges PW, Gandevia SC. Activation of the human diaphragm during a repetitive postural task. J Physiol 2000;522:165-175.
41. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med 2006;36:189-198.
42. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther 1997;77:132-142. discussion 142-134.
43. Lee K, Cho JE, Hwang DY, et al. Decreased respiratory muscle function is associated with impaired trunk balance among chronic stroke patients: a cross-sectional study. Tohoku J Exp Med 2018;245:79-88.