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Effects of trunk control robot training on balance and gait abilities in persons with chronic stroke

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Objective: To investigate the effects of training using a trunk control robot (TCR) system combined with conventional therapy (CT) on balance and gait abilities in persons with chronic stroke.
Design: Two-group pretest-posttest design.
Methods: Thirty-five subjects with chronic stroke were randomly assigned to either the TCR group (n=17) or the trunk extension-training (TET) group (n=18). Both groups performed CT for 30 minutes, after which the TCR group performed TCR training and the TET group performed trunk extension training for 20 minutes. Both groups performed the therapeutic interventions 3 days per week for 6 weeks. Balance ability was evaluated using the Berg Balance Scale (BBS), and the Timed Up-and-Go (TUG) test. Gait ability was measured using the 10 m Walk Test (10MWT) and the NeuroCom Smart Balance Master.
Results: TCR group showed significant improvements in static balance (weight bearing) and dynamic balance (weight shifting speed, weight shifting direction, BBS, and TUG), 10MWT, gait speed, and step width ($p<0.05$); step length was not significant. The TET group showed a significant partial improvement of dynamic balance (weight shifting speed, weight shifting direction, BBS, and 10MWT ($p<0.05$), but the improvements in static balance, TUG, gait speed, and step width and step length was not significant. Additionally, significant differences in static balance, dynamic balance (weight shifting speed, weight shifting direction, BBS, and TUG), 10MWT, gait speed, and step width were detected between groups ($p<0.05$).
Conclusions: TCR training combined with CT is effective in improving static and dynamic balance, as well as gait abilities in persons with chronic stroke.

Key Words: Gait, Hemiplegia, Postural balance, Rehabilitation, Robotics, Stroke

Introduction

Restoring gait ability is very important for individuals with stroke and is the primary target of most rehabilitation programs [1]. About 70% of stroke survivors can walk normally within a year after stroke, but the rest of them need assistance due to disability or being fully dependent [2]. Furthermore, stroke associated with hemiparesis results in weakness of the upper and lower limbs, as well as in impairment of balance and gait [3].

Decreased muscle strength in individuals with stroke is not limited to the upper and lower hemiparetic limbs, but also affects the trunk [4]. Sensory-motor impairment of the trunk interferes with functional performance, thus decreasing balance ability and affecting movement [5]. Increased sway during quiet standing, uneven weight distribution with increased weight bearing on the unaffected limb, decreased weight-shifting ability while in stance, and abnormalities in postural responses have been documented. A major focus of rehabilitation programs, therefore, is to improve balance and optimize function and mobility [6].

The trunk movement affects the stabilization of the spine and pelvis. However, persons with stroke suffer from weakness of the trunk and impairment of proprioception, result-

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ing in decreased balance and postural control, reduced weight-bearing ability, and increased postural fluctuations [7,8]. Because the trunk plays a central role in postural response and control, all functional movements and trunk control are important in activities of daily living [9]. Trunk control impairment leads to imbalances in sitting balance and in sit to standing ability, as well as in gait and mobility [10]. Because trunk control is related to the proximal stability, a deficit in proximal stability affects the mobility of the distal part. Therefore, decreased trunk endurance and stability impair balance and gait speed [11].

The clinical rationale for trunk control training has been well documented in people with trunk muscle weakness. The authors reported previously that inadequate sit to stand exercise is associated with the trunk muscle weakness [12]. Additionally, 10 hours of trunk training during general rehabilitation training improved the dynamics of sitting balance [13]. Enhancing trunk proprioception helps to restore sitting balance [14]. The trunk is the central key point of the body, playing an essential role for postural control, balance, the coordination of the extremities, and functional activities. Therefore, the trunk is an important component of the rehabilitation process [5].

Previous reports suggested that robotic neurorehabilitation can reduce the time and labor of the therapists and provide consistent and repetitive training [15]. In addition, robot rehabilitation can provide various treatment programs through simple manipulation, thus providing intensive training and assuring patient safety [16]. The principles of neurorehabilitation are primarily derived from motor learning theories [17]. Several principles have been proposed for better treatment outcomes in stroke survivors, including high-intensity, high repetition, task-specific activities [18-20], and active patient participation in treatment activities [21]. Regarding rehabilitation strategies, the most common robotic devices for gait restoration are based on task-specific repetitive movements, which have been shown to improve muscular strength, movement coordination, and locomotor retraining in neurologically impaired patients [22].

Recent reports in systemic reviews about trunk training on trunk control in patients suffering from stroke have shown that there is a strong amount of evidence showing that trunk training is able to improve trunk control, sitting and standing balance and mobility [23]. Therefore, we aimed to test the hypothesis that trunk control robot (TCR) system in training individuals with chronic stroke would improve their balance and gait ability.

Methods

Participants

This prospective, randomized, single-blind, controlled, pilot trial was performed in the Boramae Medical Center Rehabilitation Hospital, Seoul, South Korea. Between December 2016 and April 2017, 35 participants fulfilled the inclusion criteria and were randomly assigned to the TCR group (n=17) or the trunk extension-training (TET) group (n=18). The inclusion criteria were as follows: 1) All patients confirmed with a diagnosis of chronic stroke as defined by radiological examinations; 2) post-stroke duration of ≥12 months; 3) unilateral hemiplegia; 4) walk for 10 m or more (regardless of using assistance) and Functional Ambulation Category 3-4 level; 5) Modified Ashworth Scale score of 1 or 1^+ without injecting botulinum toxin; and 6) The Korean version Mini-Mental State Examination, ≥24 points [24]. Also, patients with cognitive, visual, or cardiorespiratory disorders (including cardiac pacemaker placement), or have received orthopedic interventions were excluded. Randomization was performed by using the ‘sealed envelope’ technique and was intended to minimize order effect. Participants were unable to consistently distinguish between TCR training and TET. The clinical therapist and data analyst were blinded to whether the patients were allocated to the experimental group or the control group. A total of 30 patients (85.7%) have completed the posttest and 5 patients (14.3%) were lost to follow-up or have discontinued the intervention (Figure 1, Table 1) presents the general baseline characteristics of the participants.

All study procedures were approved by the Institutional Review Board (IRB) of Gachon University (IRB No. 1044396-201612-HR-099-01) and registered at the Clinical Research information Service (CRiS), South Korea (KCT 0003653). All participants signed an informed consent prior to beginning the study.

Intervention

Conventional therapy

Conventional therapy (CT) was delivered by the same physical therapist to all participants in every session. Subjects from both groups completed 18 sessions performed three times per week over six weeks [25]. Subjects from the TCR+CT and TET+CT groups received 20 minutes of TCR training or TET, respectively, followed by CT for 30 minutes.

CT consisted of aerobic exercise for 10 minutes (Rehab

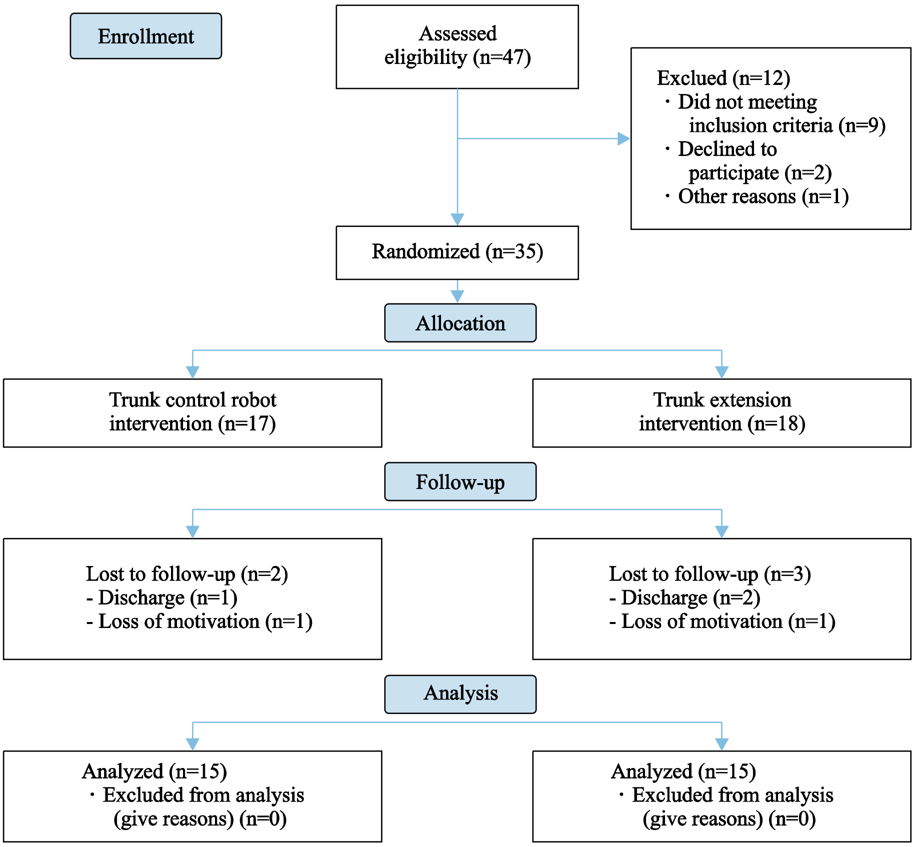

Figure 1. Flow diagram of this study. Thirty-five individuals were enrolled in the study and were randomly assigned to the Trunk control robot group (n=17) or the Trunk extension group (n=18).

Table 1. General characteristics of the two groups by randomization assignment (N=35)

Variable	TCR group (n=17)	TET group (n=18)	*p*-value
Gender (male/female)	7/10	9/9	0.60
Age (y)	61.70 (11.06)	59.72 (15.51)	0.66
Height (cm)	160.64 (8.96)	163.11 (8.74)	0.41
Weight (kg)	62.20 (9.35)	64.71 (16.23)	0.58
Paretic side (right/left)	10/7	10/8	0.39
Stroke type (infarction/hemorrhage)	12/5	12/6	0.80
Post-stroke duration (mo)	16.11 (3.01)	17.78 (3.97)	0.17
MMSE (score)	26.64 (2.02)	26.16 (1.88)	0.47
TIS (score)	13.70 (3.31)	14.72 (2.96)	0.34

Values are presented as number only or mean (SD).
TCR: trunk control robot therapy, TET: trunk extension therapy, MMSE: mini mental state examination, TIS: trunk impairment scale.

Treadmill, JT4000M, JNBMED, Goyang, Korea), isokinetic exercise at 50 revolutions per minute for 10 minutes (SCIFIT Bi-Directional Recumbent Bikes, Tulsa, OK, USA), and strengthening exercise measured individually by a smart-card system for 10 minutes (10 per minute) (5540 Leg Press Rehab, HUR, Helsinki, Finland).

Trunk control robot intervention

A TCR system (3DBT-33; Man &Tel Co., Ltd, Gumi, Korea) was used for trunk stabilization, left and right weight shift training, sit-to-stand training, and trunk correction twisting training. The robot-tilting chair used electric power to support standing up and electric robot arm function. In addition, this equipment provided correct and very effective rehabilitation based on the data and was adjusted by the subjects' active selection and will. The robot had an embedded program, which allowed the subjects to view a monitor and perform standing motion in a sitting position. When the balance between the left and right sides of the trunk was maintained, a basketball goal scene was shown on the monitor. When the ball entered the basket, the robot arm came down. The robotic tilting chair was driven, and the robot arm was pulled, so that the robot could be repeatedly be operated by the subject to stand up while sitting. The TCR allowed repeated sitting and standing exercises while maintaining trunk balance, providing motion in the sagittal plane through flexion and extension of the trunk on the midline of the body

(Figure 2).

Trunk extension intervention

TET was performed by using a pneumatic trunk strength training system (Abdomen/Back Extension Rehab 5310; HUR, Helsinki, Finland). This equipment was specifically designed to assist older adults to comfortably exercise the back and abdominal muscles for targeted core strengthening. The degree of resistance was measured by 10 repetition maximum tests, and the individual exercise form and resistance level were memorized by a smart card system. This training was performed while sitting, and the resistance bars were placed on the 5th and 6th thoracic vertebrae of the subject by adjusting the height of the chair and the angle and resistance position of the resistance bar. To prevent the compensation action of the upper extremity, both limbs were folded and placed in front of the chest (Figure 2). This training system was used for core muscle strengthening [26] and the balance and mobility [27].

Outcome measures

The subjects' general characteristics were collected by file audits and examinations. The primary outcome was balance ability and the secondary outcome was gait ability. All assessments were performed at baseline and after the 6 weeks intervention. A NeuroCom Smart Balance Master (NeuroCom International, Clackamas, OR, USA) were used for the static and dynamic balance. Each test was performed 3 times for 20 seconds, and then 10-minute rest [28]. In addition, dynamic balance was measured by the timed Up-and-Go test (TUGT) and the Berg Balance Scale [29].

Gait speed was measured by the 10 Meter Walking Test (10MWT) [30]. In addition, gait speed, step width, and step length were measured by the NeuroCom Smart Balance Master (NeuroCom International, Clackamas, OR, USA) [10].

A NewroCom Smart Balance Master system was used to measure gait ability. Measurement of gait speed, step width, and step length of the subject using the balance master can be done by gait speed (cm/sec) and step width (cm) and step length when walking from the starting point to the last part of the force plate (18 inches×60 inches) according to the GO signal indicated by the computer monitor.

Statistical analysis

A sample size using by G*Power 3.1.9.1 (Uiversität Kiel, Kiel, Germany) was estimated to be twenty-one participants per group to achieve a power of 0.8 with a significance level (α) of 0.05 using a 1-sided, 2-sample t-test and referred that 20 patients would be necessary for robotic therapy in a previous study [31].

Data analyses were used by IBM SPSS Statistics for Windows, Version 23.0 (IBM Co., Armonk, NY, USA). The Shapiro-Wilk test was used to determine the normality of the parameter. The continuous data and the categorical data were expressed as the mean±SD and as a percentage respectively. An independent t-test and the χ^2 test were used to compare the baseline characteristics of the two groups. For the change of primary and secondary outcomes within each group, pre and post intervention data were compared separately using the paired t-test and an independent t-test

Figure 2. Trunk control robot intervention used 3DBT-33 (Man & Tel Co., Ltd, Gumi, Korea) (A), Trunk extension intervention used Abdomen/Back Extension Rehab 5310 (HUR, Helsinki, Finland) (B), and Informed consent was obtained from the patient for the publication of their image.

Table 2. Changes in static balance ability within each group and between the two groups (N=30)

Static balance	TCR group (n=15)	TET group (n=15)	*p*-value
Weight bearing (%)			
Pre-test	41.73 (5.74)	44.87 (6.99)	
Post-test	48.47 (5.24)	47.00 (5.88)	
p-value	0.001*	0.123	
Changes	6.73 (6.58)	2.13 (5.04)	0.040*

Values are presented as mean (SD).
TCR: trunk control robot therapy, TET: trunk extension therapy.
*Statistically significant at $p<0.05$.

Table 3. Changes in dynamic balance ability within each group and between the two groups (N=30)

Dynamic balance	TCR group (n=15)	TET group (n=15)	*p*-value
Weight shifting Speed (degree/sec)			
Pre-test	3.24 (1.03)	4.08 (1.00)	
Post-test	5.23 (1.10)	4.33 (0.83)	
p-value	<0.001*	0.028*	
Changes	1.99 (1.20)	0.25 (0.39)	<0.001*
Weight shifting direction (%)			
Pre-test	55.47 (10.24)	48.53 (10.49)	
Post-test	64.60 (9.68)	51.87 (10.90)	
p-value	<0.001*	0.003*	
Changes	9.13 (6.12)	3.33 (3.68)	0.004*
BBS (score)			
Pre-test	36.53 (10.82)	43.67 (10.97)	
Post-test	51.27 (5.56)	47.73 (8.67)	
p-value	<0.001*	0.019*	
Changes	14.73 (10.88)	3.87 (5.64)	0.002*
TUG (sec)			
Pre-test	20.70 (9.15)	20.58 (7.98)	
Post-test	17.69 (7.91)	20.32 (7.85)	
p-value	<0.001*	0.654	
Changes	−3.01 (2.81)	−0.26 (2.18)	0.006*

Values are presented as mean (SD).
TCR: trunk control robot therapy, TET: trunk extension therapy, BBS: Berg Balance Scale, TUG: Timed Up-and-Go.
*Statistically significant at $p<0.05$.

was used for between-group comparisons. A *p*-value of less than 0.05 was considered to be significant.

Results

Regarding the static balance, the TCR group showed a significantly higher weight bearing rate on the hemiparetic lower limb compared to the TET group ($p=0.04$; effect size=0.37) (Table 2).

Table 4. Changes in gait ability within each group and between the two groups (N=30)

Gait ability	TCR group (n=15)	TET group (n=15)	*p*-value
10MWT (sec)			
Pre-test	35.38 (25.83)	24.91 (26.62)	
Post-test	12.09 (4.18)	19.40 (21.78)	
p-value	0.002*	0.026*	
Changes	−23.29 (23.90)	−5.50 (8.59)	0.014*
Gait speed (cm/sec)			
Pre-test	28.95 (14.82)	32.69 (16.24)	
Post-test	42.13 (14.80)	32.99 (17.31)	
p-value	<0.001*	0.907	
Changes	13.18 (9.74)	0.30 (9.74)	0.001*
Step width (cm)			
Pre-test	15.99 (4.47)	17.03 (2.73)	
Post-test	19.03 (2.84)	17.30 (2.56)	
p-value	<0.001*	0.907	
Changes	3.04 (4.14)	0.27 (2.40)	0.033*
Step length (cm)			
Pre-test	30.63 (10.39)	32.50 (13.03)	
Post-test	35.77 (15.57)	32.98 (12.57)	
p-value	0.138	0.893	
Changes	5.14 (12.66)	0.39 (13.94)	0.280

Values are presented as mean (SD).
TCR: trunk control robot therapy, TET: trunk extension therapy, 10MWT: 10 m Walk Test.
*Statistically significant at $p<0.05$.

Regarding dynamic balance, the weight shifting speed ($p\leq 0.001$; effect size=0.79), weight shifting direction ($p=0.004$; effect size=0.51), BBS ($p=0.002$; effect size=0.60), and TUG ($p=0.006$; effect size=0.49) of the TCR group were all significantly higher than the corresponding values of TET group (Table 3).

Regarding gait ability, 10MWT ($p=0.014$; effect size=0.54), gait speed ($p\leq 0.001$; effect size=0.56), and step width ($p=0.033$; effect size=0.39) of the TCR group increased more significantly than the corresponding parameters of the TET group. However, the step length did not change significantly in both groups ($p=0.28$; effect size=0.2) (Table 4).

Discussion

The goal of this study was to investigate the effectiveness of TCR-assisted therapy in improving balance and gait in individuals with chronic stroke. Our results indicated that TCR training combined with CT is effective in improving static and dynamic balance, as well as gait abilities in these individuals.

Previous reports showed that stabilization of the spine caused by the contraction of the abdominal and lumbar multifidus muscles plays an important role in lower limb movement [32]. Other reports also confirmed that trunk-activating exercises are important, because weakening of the trunk is related to functional performance in persons with chronic stroke. Abdominal muscle strength exercises were shown to improve gait and balance ability [33], while improvements in trunk regulation were found to increase proprioception, dynamic balance, gait speed, and symmetrical movement of the trunk during gait in stroke survivors [34].

Our results were similar to those reported by Chun *et al.* [35], who studied twenty-eight hemiplegic patients with chronic stroke who performed balance training by using a newly developed Spine Balance 3D system and the well-known Biodex Balance System 30 minutes per day, 3 times a week, for 7 weeks. They reported that the 10MWT improved significantly in the experimental group (using the Spine Balance 3D system), but not in the control group, and that the core muscle strength, which was estimated by the Spine Balance 3D system evaluation program, improved more significantly in the experimental group as well. This study confirms that balance training using the Spine Balance 3D system effectively improves dynamic balance, static balance, and gait by improving trunk muscle strength [35]. Our study also showed a significant difference in the 10MWT through trunk training, which is similar to our results in that improvement of trunk function improved balance and gait ability.

According to Rai *et al.* [36] in a comparison study, 30 patients with stroke were assessed at 6 months or more after the onset of stroke, in which the trunk rehabilitation, balance training, and conventional rehabilitation was applied to the experimental group and the control group received only the conventional rehabilitation. Two groups showed improvements in trunk control, balance ability, and gait ability. However, the experimental group achieved significant improvements in the trunk impairment scale, BBS, and 10MWT. Rai *et al.* [36] applied only traditional training to the control group and pelvic bridging exercise, range of motion exercise, and trunk rotation exercise to the experimental group.

However, the current study focused on the activation of the trunk muscles through anti-gravity training, consisting of standing up from the sitting position with the aid of the TCR system in order to match the degree, time, and condition of the intervention, while TET was applied to subjects from TET group. The BBS and the 10MWT were performed as a basic test, but dynamic balance and gait abilities were assessed by the TUG, and the influence of subjective judgment was minimized by using a highly reliable balance master. We measured the degree of weight support to determine the change in static balance and measured the speed and direction of the weight shift to detect even minimal changes in dynamic balance. Additionally, by measuring the gait speed, step width and length, dynamic balance and gait factors could be simultaneously assessed.

According to Silva *et al.* [12], who compared sit-to-stand behavior using a motion analysis system in patients with chronic stroke and healthy adults, if the momentum of the trunk forward flexion was too weak, it was compensated by the motion of limbs. As a result, it is necessary to have a natural and independent movement of the trunk when standing up from sitting position. In patients with stroke, the use of the lower extremity muscles or the use of a relatively large amount of contralateral side of the body showed dependent movement of the trunk. Therefore, from the viewpoint of kinematics of the trunk, it was reported that asymmetrical abnormal motion in the coronal and the horizontal plane was related to a small flexion momentum of the trunk in the sagittal plane [12].

In this study, the forward flexion momentum of the trunk was intended to be used by repeating the stand up from sitting position, and therefore the trunk was not used due to the compensatory action. The dynamic balance-dependent variable proved that there was a significant difference in the speed and direction of weight shift, BBS, and TUG scores. This fact suggested that the movement and training of the trunk improved balance and affected the gait. Therefore, the TCR system was able to use the forward flexion momentum of the trunk that was difficult to be used by the patients with chronic stroke when performing the sit to stand motion; consequently, rehabilitation of subjects from the TCR group was more effective than of those from the TET group, in whom training was performed only in the sitting position and the movement of the pelvis occurred when standing up from the sitting position. After all, it supports the conclusion that the movement of the trunk leads to the movement of the pelvis and affects gait. This study proved that TCR training induces a significant difference in step width, which is the variable of the gait ability.

In the study conducted by Itotani *et al.* [37], the independent gait group and the dependent gait group (in which assistive devices were used) were divided into two groups according to walking speed and the left and right weight shift ratio. A significant difference in the BBS, gait speed, and left-right weight support ratio was detected in the independent gait group. The ability to move the weight to the paralyzed side during walking was an important factor in achieving independent walking ability [37]. In our study, both groups showed improvements in the BBS, suggesting that both methods may effective trunk control. A recent systematic review already suggested that trunk training seems to be effective in restoring symmetry in muscle thickness of the transversal abdominal muscles and improve the muscle activity of the internal oblique abdominis, which might explain the increased stability in the trunk [38]. Also the changes in static balance and dynamic balance were measured by weight bearing and the speed and direction of the weight shift, while changes in gait ability were measured by the 10MWT, gait speed, step width, and step length. The TCR training was found to improve balance and gait ability. According to Saeys *et al*. [27], improved trunk control has a carry-over effect on dynamic balance after trunk control training, and that the trunk stability is essential for limb movement. Therefore, similar to the previous study, our study showed the balance and gait ability improved through the TCR training.

In this study, there were clinically significant effect sizes and large power for detecting statistically significant changes in the weight shifting speed (effect size=0.79), weight shifting direction (effect size=0.51), and BBS (effect size=0.60). In addition, there were clinically significant effect sizes for weight bearing rates on hemiparetic lower limb (effect size=0.37), TUG (effect size=0.49), and step width (effect size=0.39), but the powers were medium.

This study had several limitations. First, the TCR system was applied to all subjects, regardless of the general characteristics of the subject, such as gender, age, height, and weight. Although tools of various difficulties were provided according to the general characteristics of the subjects and various parameters of the tool were changed according to individual balance and the gait ability, there was a limit in providing diversity. This had led to some difficulties in adapting to training for each subject and difficulties with the same application. Therefore, further studies will need to take this point into account. Second, the number of subjects was small, and the condition of subjects was limited to chronic stroke, which limited the generalization of the results of the TCR training. Future studies should assess obtained results on a larger cohort of subjects with various durations from the stroke onset. Moreover, it will be necessary to compare the effects of applying the TCR training by classifying patients into acute and sub-acute stroke groups. Finally, further studies are needed to confirm the suitability of training method of the trunk by long-term follow-up of TCR training by setting longer experimental study periods. In consideration of the above problems, a more detailed training method should be provided to identify various effects of this method.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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