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# Co-Contraction of Lower Limb Muscles Contributes to Knee Stability During Stance Phase in Hemiplegic Stroke Patients

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Study Design A  
Data Collection B  
Statistical Analysis C  
Data Interpretation D  
Manuscript Preparation E  
Literature Search F  
Funds Collection G

ACEF **Hai Yuan\***  
BDE **Pingping Ge\***  
BF **Lingling Du**  
AE **Qing Xia**

Department of Rehabilitation Medicine, The Second People's Hospital of Hefei City,  
Hefei, Anhui, P.R. China

**Corresponding Authors:**  
**Source of support:**

\* Hai Yuan and Pingping Ge contributed equally to this paper  
Hai Yuan, e-mail: haiyuan103@163.com, Qing Xia, e-mail: xiaqing233921@yeah.net  
Departmental sources

**Background:** Knee stability has an important role in the gait of hemiplegic stroke patients. However, factors affecting knee stability have not been assessed concerning gait. The purpose of this study was to explore whether co-contraction of the lower limb muscles contributes to the knee stability during the stance phase of the gait cycle in hemiplegic stroke patients.

**Material/Methods:** A total of 30 hemiplegic stroke patients, ages 36–79 years, were instructed to walk at their natural speed. The root mean square of surface electromyography was used to measure activities of the biceps femoris and rectus femoris muscles, while the co-contraction ratio was computed based on the root mean squares. The peak angle of knee extension was acquired in the stance phase by 3D kinematic analyses. Lower limb function was evaluated using the Fugl-Meyer scale for lower limb motor assessment.

**Results:** A statistically significant increase of the muscle co-contraction ratio of the involved extremity was observed compared with that of the uninvolved extremity ( $t=-4.066$ ,  $P<0.05$ ). The muscle co-contraction ratio was significantly correlated with the peak angle of knee extension ( $r=0.387$ ,  $P=0.035$ ), Fugl-Meyer scale ( $r=-0.522$ ,  $P=0.003$ ), and Modified Ashworth Scale ( $r=0.404$ ,  $P=0.027$ ) during the stance phase of the gait cycle.

**Conclusions:** Our results showed that co-contraction of the rectus femoris muscle contributes to the stability of the knee and lower limb function in hemiplegic stroke patients, and suggests that co-contraction should be considered in the rehabilitation of knee stability during gait in hemiplegic stroke patients. Appropriate rehabilitation assessment planning with hemiplegic stroke patients, such as muscle co-contraction or knee stability of, might be created based on our results.

**MeSH Keywords:** **Gait • Hemiplegia • Knee • Muscle Hypertonia • Stroke**

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## Background

Stroke is a persistent neurological impairment resulting from cerebrovascular disease [1], and it is the focal cause of motor impairments in paretic limbs that interferes with the ability to control balance, such as sitting-up, standing, and walking [2]. The decreased balance and disability of stroke patients mainly results from decreased muscle power and abnormal muscle co-contraction [3,4], and stroke-related sarcopenia, which is identified by fiber-type shift, disuse atrophy, and malnutrition of muscles [5,6]. In stroke patients, the knee is more vulnerable than the other lower-limb joints. The reduction of knee flexion during the swing phase has been observed based on the abnormal stiff-knee gait [7]. Abnormal and excessive activation of the rectus femoris, which is a primary cause of stiff knee occurs, and the insufficient biceps femoris activation is considered to be related with reduced knee flexion in hemiplegic stroke patients [8, 9]. Motor control depends on precisely timed and appropriately modulated synergy between agonist and antagonist muscles [10]. Abnormal muscles synergy is the major cause of decreased dynamic balance and slowed gait [11]. Therefore, it is important to determine whether the abnormal muscles synergy contributes to motor control disorders, such as knee control, in the gait of hemiplegic stroke patients.

Muscle co-contraction is the simultaneous activity of antagonist muscle crossing the same joint during agonist muscle contraction [12]. It has been confirmed that the co-contraction of antagonist muscles is exaggerated in stroke patients, and is positively associated with spasticity, defined as the velocity-dependent increased muscle tone [13]. Abnormal muscle co-contraction is considered an important factor that limits functional recovery in stroke patients [14] and has an important role in providing optimal joint stability during walking in patients with Parkinson's disease [15]. Previous studies have measured muscle co-contraction patterns of the hemiplegic limb by surface electromyography (sEMG) [16,17], revealing that co-contraction of agonist and antagonist muscles significantly delays the initiation of muscle contraction during walking [18]. However, it has been not determined whether muscle co-contraction contributes to the stability of hemiplegic gait in stroke patients. An association of decreased lower-limb muscle activation with reduced knee flexion has been found during the stance-to-swing phases of post-stroke gait [19]. However, muscle co-contraction and knee stability have been not been explored during the stance phase of hemiplegic gait.

The main purpose of this study was to analyze the relationship between muscle co-contraction and knee extension or lower limb function to determine whether the co-contraction of the lower limb muscles contributes to knee stability during the stance phase of the gait cycle in hemiplegic stroke patients.

## Material and Methods

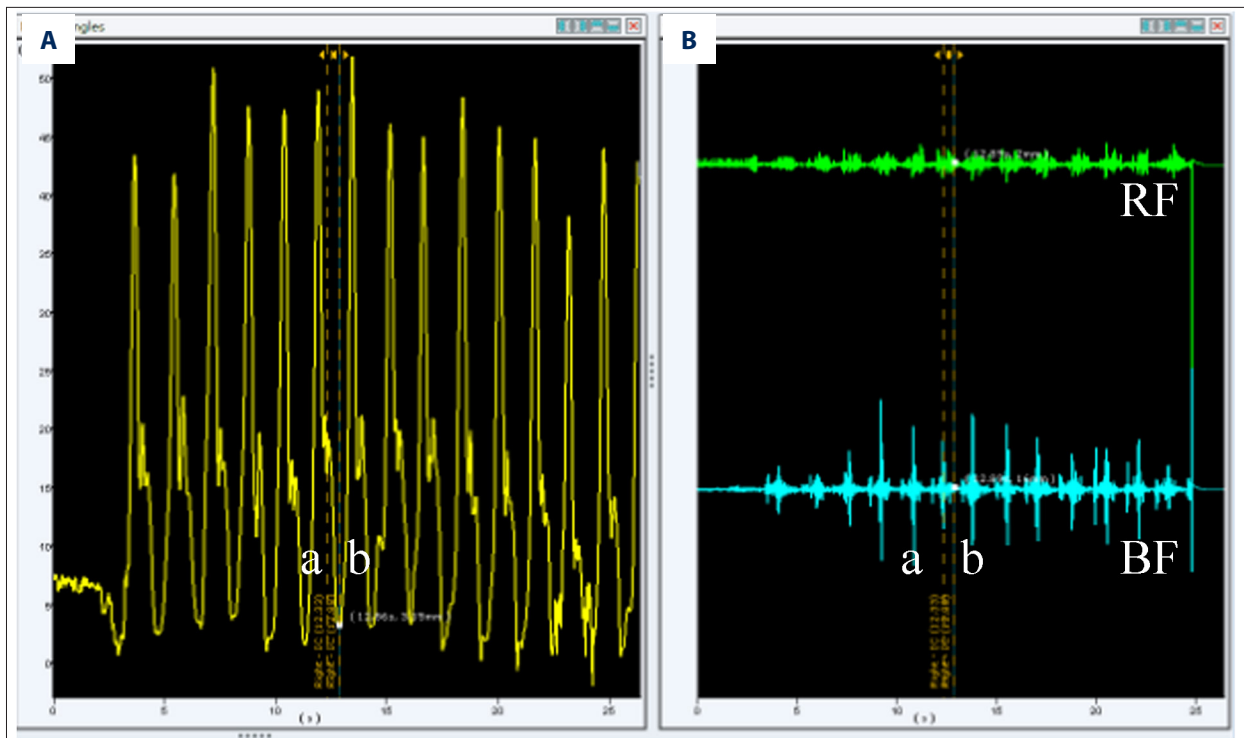
This study received approval from the Ethics Committee of Second People's Hospital of Hefei City and was conducted according to the Declaration of Helsinki. Testing of subjects took place at the Motor Control Research Laboratory at the Department of Rehabilitation Medicine of Second People's Hospital of Hefei City. The purpose and content of the study were communicated and written informed consent was obtained from all participants.

We included a total of 30 hemiplegic stroke inpatients – 23 males and 7 females, ages 36–79 years at Second People's Hospital, Hefei, China between September 2016 and April 2018. Inclusion criteria were as follows: 1) the stroke was defined according to the National Institute for Neurological and Communicative Disorders and Stroke/Alzheimer's Disease and Related Disorders Association criteria [20]; 2) Brunnstrom III–IV stages and the patient could walk independently; 3) no limited dorsal ankle flexion; and 4) Mini-Mental State Examination scores >24 [21]. Exclusion criteria were: 1) patients with knee spasticity caused by other CNSs or extra-pyramidal signs; 2) other diseases of the lower extremity, such as acute sprains, history of surgeries, joint replacements, and pain; and 3) patients with severe cardiopulmonary diseases.

Changes in muscle functional status, multi-muscle coordination, and muscle strength level were quantitatively assessed by sEMG [22]. EMG signals can quantitatively reflect changes in muscular activity and the features of dysfunction of nervous control with cerebral palsy patients [23]. Root mean square (RMS) and RMS of all amplitudes during a certain time are representative of the average change in the discharging of muscle and nerve during this time [24]. RMS is considered as the most reliable parameter in the time domain to estimate the feature of muscle contraction based on the recruitment of motor units and the synchronization of an excited rhythm [25].

sEMG Electrodes (Ag-AgCl, 2 cm among 2 active sites and 1 reference electrode) were placed over the muscle belly after appropriate skin preparation. Before positioning the probes, local skin keratinocytes were removed by sandpaper and 75% alcohol was used for defatting. Subjects were asked to walk barefoot for 5 min at natural speed and cadence. A 3–5 min training session was provided before the test to familiarize patients with the testing process.

3D gait analysis has been widely used in clinical fields due to the high accuracy and objectivity of its assessment parameters. The human gait patterns of various movement disorders such as stroke have been accurately assessed by 3D gait analysis [26–28]. 3D gait analysis can quantitatively evaluate the spatiotemporal and kinematic characteristics of gait cycle to



**Figure 1.** (A) The measured knee angle. (B) The activation patterns of rectus femoris and biceps femoris were simultaneously exhibited by sEMG during hemiplegic gait. The dotted line a is representative of the initial foot strike and b is representative of the peak angle of knee extension in the stance phase. RF – rectus femoris; BF – biceps femoris.

identify the minimal gait abnormalities [29,30]. The reproducibility of movement assessment for 3D gait analysis has been assessed in stroke patients [31].

The peak range of knee extension, hip extension, and ankle plantar flexor between the initial foot strike (Figure 1, the dotted line a) and the peak of knee extension (Figure 1, the dotted line b) in the stance phase were measured by 3D kinematic analysis (Codamotion CX4, Charnwood Dynamics, England) (Figures 2, 3). The value in peak knee extension angle was used during hemiplegic gait with stroke patients.

sEMG data acquisition was performed and analyzed using a ME6000 T8 surface EMG (Mega Electronics, Kuopio, Finland) and MEGA Win2.4 analysis software. The parameters were set up as follows: a sampling rate of 1000 Hz, CMRR (common mode rejection ratio) of 110 dB, input impedance <5 G, amplified 1000 times by the amplifier, the noise level <1  $\mu$ V. The original data were stored in the computer by processing signals with a 14-bit analogue-to-digital converter (AID), the analysis window was set at 1024 $\times$ 768 resolutions and the degree of overlap was set to 50% [22].

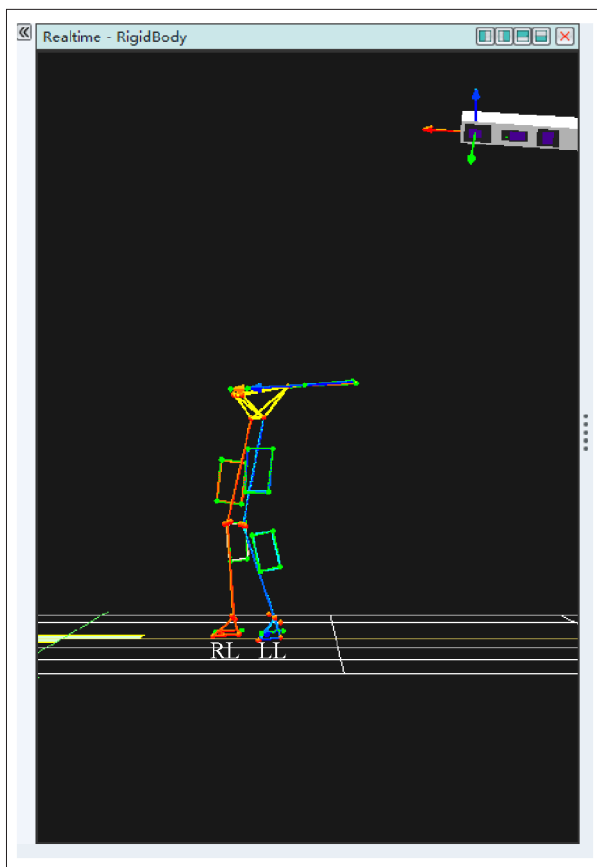
sEMG data were used to simultaneously measure biceps femoris and rectus femoris activity between the initial foot strike and the peak knee extension during the stance phase of the gait cycle.

Based on the 3D kinematic analysis, the relevant valuables were compared between the initial foot strike and peak knee extension.

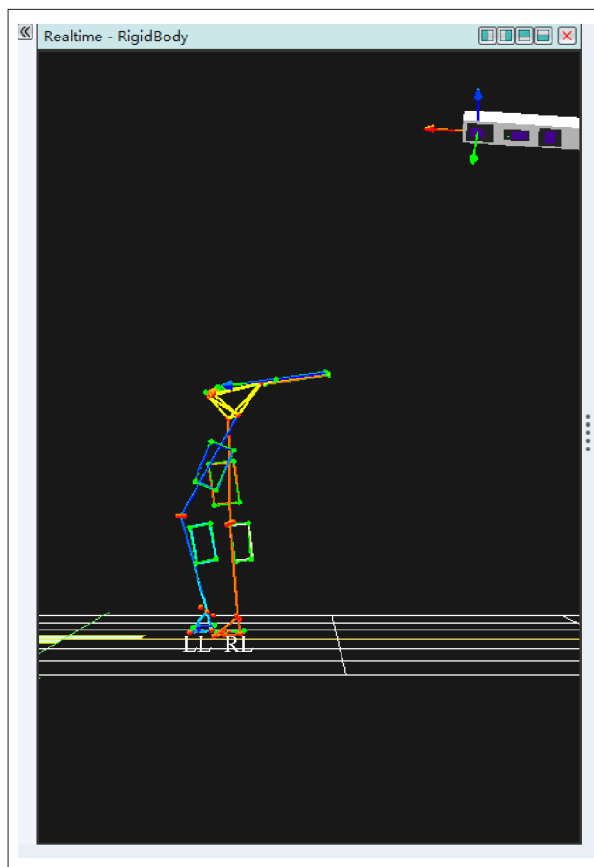
The electromyographic signals of the biceps femoris and rectus femoris muscles were analyzed between the involved and uninvolved extremities, and RMS was acquired using MEGA Win 2.4 analysis software. The co-contraction ratio (CCR) was computed as follows: the biceps femoris RMS value was set as 100% and rectus femoris activation that occurred during this time was computed as a percentage of this value [32]. The lower limb functions were evaluated by Fugl-Meyer lower limb motor assessment (FMA) and Modified Ashworth Scales (MAS).

#### Statistical analysis

Kolmogorov-Smirnov test was used to determine if the parameters were normally distributed. Data were expressed as means  $\pm$  standard deviations for normal distribution. The paired *t* test was used to compare CCR and joint angles between the involved and uninvolved extremities, and Pearson correlation coefficient was used to evaluate the correlation between CCR and peak angle knee extension or FMA. Spearman rank correlation was used to explore the relationship of CCR with MAS. A 2-sided *p* value of 0.05 was considered statistically significant. SPSS16.0 software (SPSS, Inc., Chicago, IL) was used for all analyses.



**Figure 2.** The time point of the initial foot strike (RL) was shown by 3D kinematic analyses during hemiplegic gait following stroke. RL – right leg; LL – left leg.



**Figure 3.** The time point of the peak angle of knee extension (RL) was showed by 3D kinematic analyses during hemiplegic gait following stroke. RL – right leg; LL – left leg.

**Table 1.** Comparison of the peak angle of hip extension, ankle plantar flexor, and CCR during hemiplegic gait in stroke patients (means ± standard deviations).

Angles	Group		t Value	p Value
	Affected limbs	Unaffected limbs		
Hip extension	-13.613±9.398	-13.228±10.068	-0.345	0.733
Ankle plantar flexor	-1.808±7.624	1.552±8.651	-1.785	0.085
CCR	1.231±0.433	1.148±0.431	-4.066	0.000

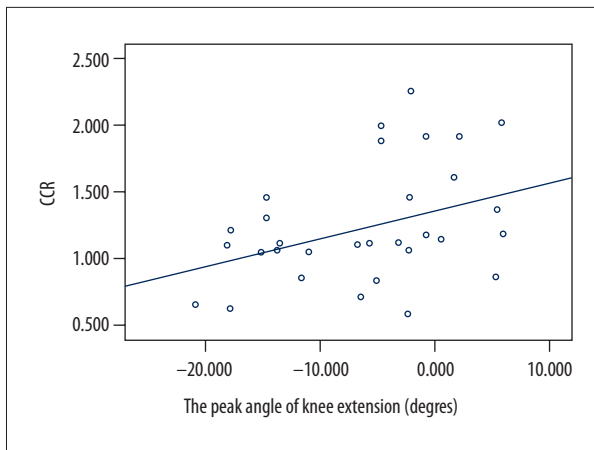
**Table 2.** Correlation between co-contraction and the peak of knee extension, FMA, or MAS.

	r	p Value
Peak of knee extension	0.387	0.035 <0.05
FMA	-0.522	0.003 <0.05
MAS	0.404	0.027 <0.05

## Results

### Correlation between CCR angles in the affected and unaffected lower limbs

The excess rectus femoris co-contraction occurred during the stance phase of the gait cycle. The CCR was increased in the tested muscles of the affected lower limb compared with that of unaffected side in patients between the initial foot strike and the peak of knee extension. The observed difference was statistically significant ( $t=-4.066$ ,  $P<0.05$ ), and suggested that



**Figure 4.** Scatter plot of CCR versus the peak angle of knee extension during the stance phase of the gait cycle in hemiplegic stroke patients.

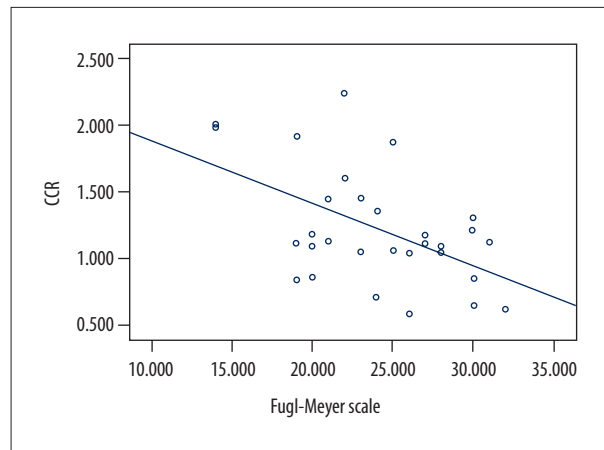
there is an excessive co-contraction of the rectus femoris with stroke-related hemiplegic lower limb. No significant difference was observed between the affected side and the unaffected side for the peak angle of hip extension ( $t=-0.345$ ,  $P>0.05$ ) or ankle plantar flexor ( $t=-1.785$ ,  $P>0.05$ ). Details are provided in Table 1.

#### Correlation between CCR and the peak angle of knee extension

The peak angle of knee extension was positively correlated with the CCR ( $r=0.387$ ,  $P=0.035<0.05$ ), and a statistically significant correlation between CCR and the peak angle of knee extension was demonstrated (Table 2), which indicated that the excessive co-contraction of the rectus femoris muscle weakens knee stabilization during the stance phase of the gait cycle. The corresponding scatter plot is shown in Figure 4.

#### Correlation between CCR and FMA or MAS

Fugl-Meyer lower-extremity motor assessment based on the hemiplegic limb synergy patterns is widely used to assess stroke-inducing lower-limb function. Higher Fugl-Meyer scores are positively associated with hemiplegic limb recovery in stroke patients [33], but MAS has a negative association [34]. We found a statistically significant negative relation between the CCR and affected lower-extremity motor function of FMA ( $24.000\pm 4.799$ ) ( $r=-0.522$ ,  $P=0.003<0.05$ ) (Figure 5), and a positive association between MAS and CCR was found ( $r=0.404$ ,  $P=0.027<0.05$ ) (Table 2). The results suggest that the observed CCR in the post-stroke hemiplegic lower limb is negatively correlated with limb functional recovery.



**Figure 5.** Scatter plot of CCR versus FMA during the stance phase of the hemiplegic gait following stroke patients.

## Discussion

Muscle co-contraction is defined as the simultaneous contraction of agonist and antagonist muscles crossing a joint [35]; this has an important role in movement regulation and maintenance of joint stability [36]. Nevertheless, pathological co-contraction influences limb motor function during active movement. A correlation between co-activation patterns of muscles and functional outcome measures has been shown in paretic limbs [37]. Accordingly, spasticity is considered to be an exceptional form of increased muscle tone [38]. Sin et al. confirmed that the co-contraction of antagonist muscles is exaggerated and is related with spasticity during recovery on hemiplegic stroke patients [39]. Leonard et al. revealed that increased co-contraction is observed in the hemiplegic limbs of stroke patients during functional movement, and that the CCR is positively correlated with modified Ashworth scores [32]. There is increased knee co-contraction on the paretic side during the stance phase in chronic stroke patients [40]. Therefore, the co-contraction should be considered as an effective alternative method for assessment of abnormal muscle tone during the stance phase of the gait cycle in hemiplegic stroke patients. We found that the co-contraction rate of the rectus femoris was higher on the affected side than on the unaffected side, which suggests that rectus femoris contraction is stronger than biceps femoris contraction on the affected side. In addition, there was a positive relationship of CCR with MAS in hemiplegic lower limbs during gait in stroke patients. These results were compatible with the traditional theoretical concept. In stroke patients, the reciprocal inhibition between agonists and antagonists is broken [41] and there are abnormal muscle synergies between antagonistic muscles in paretic limbs. The spastic antagonistic muscles produce exaggerated activity due to lack of reciprocal inhibition, resulting in dysfunctional co-contraction [42].

The muscle synergy in post-stroke patients induces distinctive and complex movement patterns that affect limb stability and movement capacity [43]. After a stroke, the changes in muscle tone and postural balance deteriorate the gait performance in hemiplegic patients [44]. Leonard et al. demonstrated a correlation between the co-activation patterns of muscles and functional outcome measures in paretic limbs [32]. In chronic stroke patients, the flexor synergy is often manifested as a complex pattern that, together with spasticity, affects joint movement patterns [18,45]. Our results, which are in line with the above reported studies, show that the CCR has an association with the FMA, suggesting that CCR has an essential role in the evaluation of lower extremity function in hemiplegic stroke populations. Ohn et al. reported that muscle contraction patterns are positively correlated with spasticity of the elbow flexor ( $r=0.944$  on shoulder flexion,  $r=0.741$  on hand grasping,  $p<0.01$ ) and negatively correlated with functional recovery of the upper limb ( $r=0.670$ ,  $p<0.05$ ) [43], which should be taken into account by rehabilitation programs.

The knee pattern revealed the presence of knee hyperextension during midstance in a large percentage of hemiplegic stroke patients [46]. Pinzur et al. found that the spastic deformity is characterized by an equinus position of the ankle, hyperextension of the knee, and increased flexion of the hip during stance phase [47]. Moreover, Braendvik et al. reported that lower limb function is an important factor related with stroke gait performance [48]. However, the relevant factors that contribute to the stability of hemiplegic gait in stroke patients should be further investigated. In the present study, the increased CCR was positively correlated with the motor angle of knee extension in the affected lower limb. The positive correlation between spasticity and muscle co-contraction has also been observed in hemiplegic stroke patients [43]. Therefore, the indirect evidence implies that spasticity or hypertonia of the rectus femoris muscle might cause decreased stability of knee extension during the stance phase. Bovonsunthonchai et al. have showed that excessive activation of the quadriceps causes a mass knee extension pattern during the stance phase [44]. This suggests ways that therapists could improve the treatment of these patients.

It has been reported that increased muscle tone of ankle plantar flexors can significantly affect the stance phase of the gait cycle [49]. Galli et al. found higher dorsiflexion during stance phase in hemiplegic stroke populations [46]. The existing

literature presents findings similar to those observed in our study [50]. The excessive knee extension may be related to spasticity of the ankle plantar flexor or contracture of the plantar flexor [51]. Kobayashi et al. found that ankle plantarflexion contractures are associated with increased knee extension during the stance phase [52]. Muratli et al. reported that knee hyperextension may be caused by spasticity of the plantar flexor [53]. These observations support the link between ankle plantarflexion contractures and increased knee extension. In addition, Barroso et al. asserted that the desired hip flexion is obstructed because of the increase in knee extension, and an increased hip flexion is characteristic for stroke patients with genu recurvatum [54]. During the stance phase, the angles of hip extension and ankle plantar flexor on the affected side were not significantly different from those of the unaffected side, so we may have failed to consider the effect of hip and ankle motor functions on knee stability. This study has some other limitations. The first is the small sample size based on the non-normal distribution of the assessed variables, which should be addressed by further studies with larger sample sizes. The second is that synergy and spasticity patterns might not be associated with limb dominance. In this study, the possible effect of limb dominance was not completely prevented from influencing the results. In addition, this was a single-center study; therefore, findings of this study cannot be generalized to a wider population.

## Conclusions

Our results showed that co-contraction of the lower limb muscle should be considered as an objective and quantitative assessment method of abnormal muscle tone in hemiplegic stroke patients. Our results show that muscle co-contraction contributes to stabilization of the knee joint and lower-limb function in hemiplegic stroke patients, and suggests co-contraction should be considered in rehabilitation of knee stability during gait in hemiplegic stroke patients. The appropriate rehabilitation management plans, such as intervention studies of muscle co-contraction or knee hyperextension, might be formulated based on our results.

## Conflict of interest

None.



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