



Original Article

## Is the diaphragm thickness related to gait speed in patients with hemiplegia caused by cerebrovascular accident?

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**Abstract.** [Purpose] We aimed to determine the relationship between gait speed and diaphragm thickness in community-residing patients with hemiplegia caused by cerebrovascular accidents. [Participants and Methods] We recruited 11 elderly participants (six male and five female, mean age  $71.1 \pm 13.6$  years) from an outpatient rehabilitation unit. The inclusion criteria were as follows: patients with hemiplegia caused by cerebrovascular accidents, those able to walk without assistance, and those able to understand our instructions. We measured the diaphragm thickness on both the paretic and non-paretic sides in each participant during maximum exhalation and inhalation during three laboured breaths by ultrasonography with a 7.5-MHz linear scanner. The linear scanner was placed on the eighth or ninth rib between the anterior and middle axillary lines. And their gait speed was measured during a 10 m walk. [Results] There was a strong positive correlation between gait speed and the ratio of diaphragm thickness between the paretic and the non-paretic sides during maximal inspiration. The other measured parameters did not show significant correlation with gait speed. [Conclusion] The symmetrical thickness of the diaphragm is a key factor in increasing gait speed in patients with hemiplegia. These findings may contribute to the development of trunk muscle strength-training programs that improve trunk function and gait speed in patients with hemiplegia.

**Key words:** Patients with hemiplegia caused by cerebrovascular accident, Diaphragm, Gait speed

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### INTRODUCTION

Due to the rapidly aging society, the number of elderly people requiring long-term care is increasing in Japan. According to the Annual Report on the Aging Society 2019<sup>1)</sup>, by the Cabinet Office, the population aged above 65 years was 35.89 million. This comprises 28.4% of the total Japanese population, and this is the highest proportion of aged people in a population globally. The National Life Basic Survey by the Ministry of Health, Labour, and Welfare in 2019 released the ranking of the causes for long-term care. The most common cause was dementia (17.6%), followed by cerebrovascular accident (16.1%) in the elderly population. For patients with hemiplegia caused by cerebrovascular accident residing in the community, a restricted movement within the community environment may lead to a decrease in activity, level of independence, quality of life, and self-efficacy<sup>2)</sup>. Consequently, these factors increase the need for long-term care. The movement ability in the community environment for patients with hemiplegia caused by cerebrovascular accident relates to their gait speed<sup>3-5)</sup>, and decreased gait speed may interfere with walking independently<sup>6, 7)</sup>. In recent years, studies have shown that the gait speed af-

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fects health conditions<sup>8</sup>), and there is a strong relationship between the gait speed and survival rate<sup>9</sup>). Hence, focusing on gait speed is an essential parameter for health, regardless of the disease status. The gait speed in patients with hemiplegia caused by cerebrovascular accident depends on the function of the lower limbs and the trunk<sup>10-14</sup>). Verheyden et al.<sup>15</sup>) illustrated the importance of trunk function; patients with hemiplegia caused by cerebrovascular accident showed a decline in trunk function, which was strongly related to their gait speed. Patients with hemiplegia caused by cerebrovascular accident develop dysfunction of the diaphragm, which is a core muscle of the trunk. Therefore, such patients have difficulty in maintaining trunk stability and postural control during movements<sup>16-18</sup>). However, rehabilitation training for the diaphragm can contribute to improve in postural control during movements in patients with hemiplegia caused by cerebrovascular accident<sup>18, 19</sup>). A significant correlation between gait speed and the Trunk Control Test and Trunk Impairment Scale has been reported<sup>15</sup>). Yoon et al.<sup>19</sup>) described a significant correlation between gait ability and the Functional Ambulation Category, which is a clinical index of gait ability based on the amount of assistance. Few studies have investigated the relationship between gait ability and diaphragmatic function in patients with hemiplegia caused by cerebrovascular accident. This study focused on the diaphragm, which is clinically important for maintaining the trunk function in patients with hemiplegia caused by cerebrovascular accident. We aimed to determine the relationship between gait speed and thickness of the diaphragm.

## PARTICIPANTS AND METHODS

Eleven participants were recruited from elderly patients who attended the outpatient rehabilitation centre. All participants were community residents and could walk without assistance from any person and could understand our instructions. Their attributes are shown in [Table 1](#). Ethical approval for the study was granted by the Ethics Committee of Kanazawa Orthopedics Sports Medicine Clinic (Kanazawa-OSMC-2019-001), and all participants and their families were provided all information regarding this study, and the participants signed an informed consent form.

The diaphragm thickness was measured using a B-mode ultrasonographic apparatus (SSD-3500SV; Hitachi Aloka Medical, Japan) with a 7.5-MHz liner scanner. Participants were asked to lie in the supine position on a plinth. The liner scanner was placed on the eighth or ninth rib between the anterior and middle axillary lines (zone of apposition)<sup>20, 21</sup>). The diaphragm thickness on both the paretic and non-paretic sides were measured during maximal exhalation and inhalation during three laboured breaths, and their average values were calculated. The mean of the measured diaphragm thickness was normalized based on each participant's weight. The diaphragm thickness at maximal inhalation and the amount of change in thickness (maximal inhalation diaphragm thickness – maximal exhalation diaphragm thickness) were calculated for both the paretic and non-paretic sides. Furthermore, to compare the symmetry of the thickness between the paretic and non-paretic sides, the diaphragm thickness at maximal exhalation and maximal inhalation were calculated, respectively, as follows: diaphragm thickness on the non-paretic side / diaphragm thickness on the paretic side × 100. To measure the 10-meter walk, the participants were asked to walk for 14 m, including a 2-m runway at the starting point and a 2-m deceleration way at

**Table 1.** Demographic information

Gender	Male: 6 Female: 5
Age (years)	71.1 ± 13.6
Height (cm)	154.4 ± 9.2
Weight (kg)	56.9 ± 11.6
Diagnosis	Cerebral hemorrhage: 4 Cerebral infarction: 7
Paretic side	Right: 7 Left: 4
Brunnstrom Recovery Stage (upper extremity)	II: 2 III: 1 IV: 1 V: 3 VI: 4
Brunnstrom Recovery Stage (lower extremity)	III: 2 IV: 2 V: 3 VI: 4
Period from onset (years)	7.3 ± 4.5
Mean value ± Standard Deviation (SD).	

the finishing points to measure the free gait speed. All participants walked twice, and the average time was calculated. All statistical analyses were performed using SPSS software (version 21.0; IBM, Japan). The association between free gait speed and diaphragm thickness was investigated by calculating Spearman's correlation coefficient. The level of significance was set at  $p < 0.05$ .

## RESULTS

The mean diaphragm thickness at maximal exhalation and maximal inhalation, the change amount in diaphragm thickness, and the ratio of symmetry in diaphragm thickness at maximal exhalation and inhalation between the paretic and non-paretic sides, and the gait speed are shown in Table 2. There was a strong significant correlation between gait speed and the ratio of the diaphragm thickness between the paretic and non-paretic sides on maximal inhalation ( $r = 0.892$ ,  $p < 0.05$ ). Other values did not show a significant correlation with gait speed (Table 3).

**Table 2.** Values of diaphragm thickness and gait speed

Diaphragm thickness on the paretic side	
Maximal exhalation (mm/kg)	0.037 ± 0.013
Maximal inhalation (mm/kg)	0.054 ± 0.017
Diaphragm thickness on the non-paretic side	
Maximal exhalation (mm/kg)	0.039 ± 0.015
Maximal inhalation (mm/kg)	0.060 ± 0.020
The amount of change in diaphragm thickness (maximal inhalation diaphragm thickness – maximal exhalation diaphragm thickness)	
The paretic side (mm/kg)	0.018 ± 0.021
The non-paretic side (mm/kg)	0.011 ± 0.011
The ratio of symmetry in diaphragm thickness (diaphragm thickness on the non-paretic side / diaphragm thickness on the paretic side × 100)	
Maximal exhalation (%)	105.0 ± 15.3
Maximal inhalation (%)	90.8 ± 9.0
Gait parameter	
Gait speed (m/s)	0.66 ± 0.26

The mean of the measured diaphragm thickness (mm) was normalized based on each participant's weight (kg). Mean value ± Standard Deviation (SD).

**Table 3.** Correlation between diaphragm thickness and gait speed

	Gait speed
Diaphragm thickness on the paretic side	
Maximal exhalation	0.05
Maximal inhalation	0.09
Diaphragm thickness on the non-paretic side	
Maximal exhalation	-0.29
Maximal inhalation	-0.04
The amount of change in diaphragm thickness (maximal inhalation diaphragm thickness – maximal exhalation diaphragm thickness)	
The paretic side	0.26
The non-paretic side	-0.12
The ratio of symmetry in diaphragm thickness (diaphragm thickness on the non-paretic side / diaphragm thickness on the paretic side × 100)	
Maximal exhalation	-0.30
Maximal inhalation	0.89*

\* $p < 0.05$ .

## DISCUSSION

To the best of our knowledge, this is the first study to investigate the relationship between gait speed and diaphragm thickness in patients with hemiplegia caused by cerebrovascular accident residing in the community. We found a strong correlation between gait speed and the ratio of diaphragm thickness between the paretic and non-paretic sides at maximal inhalation, while other parameters did not show a significant correlation with gait speed. These findings suggest that symmetrical thickness of the diaphragm is a key factor in increasing gait speed. The more significant asymmetry gait shows slower gait speed in patients with hemiplegia caused by cerebrovascular accident<sup>22</sup>). Kolar<sup>23</sup>) developed dynamic neuromuscular stabilization to facilitate diaphragm function. This training can achieve symmetrical diaphragmatic movements and activation of the deep muscles in the trunk<sup>19</sup>). Kolar<sup>24</sup>) reported that dynamic trunk stabilization was required for optimal performance. This cannot be achieved by strength training of single muscle groups such as the neck-deep flexors, abdominals, back extensors, and gluteus. Additionally, the accurate coordination of these muscles and regulation of the intra-abdominal pressure by the central nervous system is required simultaneously.

The dynamic trunk stabilizing muscles, including the diaphragm, constitute the “deep core” and operate under the automatic and subconscious “feed-forward control mechanism” and precedes any purposeful movement<sup>25–28</sup>). The optimal activation of the diaphragm increases the intra-abdominal pressure equally in all directions and consequently leads to activation of the muscles of the trunk<sup>23</sup>). Therefore, symmetrical activation of the diaphragm is a basic necessity for the dynamic stabilization of the trunk. Tayashiki et al.<sup>29</sup>) revealed that the highest hip extension torque occurred during breath-hold at maximal inspiration compared to that during breath-hold at maximal exhalation and under breath-hold at normal conditions. This suggests that activation of the inspiratory muscles, including the diaphragm, produces higher intra-abdominal pressure. In the current study, there was a strong correlation between gait speed and the ratio of diaphragm thickness between the paretic and non-paretic sides at maximal inhalation. Patients with hemiplegia caused by cerebrovascular accident with symmetrical activation of the diaphragm had a relatively good trunk function and higher control of postural movements; therefore, they could increase their gait speed. The limitations of this study were that we focused only on the diaphragm among the dynamic trunk stabilizing muscles and we only measured muscle thickness. Further research is necessary to assess other muscles related to dynamic trunk stabilization, namely, transverse abdominis, multifidus, and pelvic floor muscles. For more robust results, not only the muscle thickness but also echo brightness, amount of movement, and electromyographic activity of the muscles should be assessed. Moreover, to determine the contribution of the diaphragm to gait speed, a larger number of participants are necessary, and interventional or longitudinal studies are important. In conclusion, symmetrical activation of the diaphragm appears to be a key factor in improving gait speed. This finding may contribute to the development of rehabilitation programs for strength training and improving the function of the muscles of the trunk in patients with hemiplegia caused by cerebrovascular accident residing in the community.

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### Conflict of interest

There are no conflicts of interest to declare.

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