



Original Article

## Gait improvement in stroke patients by Gait Exercise Assist Robot training is related to trunk verticality

KEITA AIMOTO, RPT, MS<sup>1)\*</sup>, TAKAYUKI MATSUI, RPT<sup>1)</sup>, YUSUKE ASAI, RPT<sup>1)</sup>, TAKU TOZAWA, RPT<sup>1)</sup>, TOMOYA TSUKADA, RPT<sup>1)</sup>, KOKI KAWAMURA, RPT, MS<sup>1)</sup>, KENICHI OZAKI, MD, PhD<sup>1)</sup>, IZUMI KONDO, MD, PhD<sup>1)</sup>

<sup>1)</sup> Department of Rehabilitation Medicine, National Center for Geriatrics and Gerontology: 7-430 Morioka-cho, Obu-shi, Aichi 474-8511, Japan

**Abstract.** [Purpose] Various types of Gait Exercise Assist Robot (GEAR) have been developed recently, some of which have enabled early improvement in patients with stroke. However, none has yet resulted in independent walking in these patients. Hence, we conducted an exploratory study of the effect of GEAR on achieving independent walking in stroke patients. [Participants and Methods] The participants were 16 patients with severe stroke. We evaluated patients' ability to walk independently after GEAR training. The outcome measure was Stroke Impairment Assessment Set (SIAS) motor score (Hip Flexion, Knee Extension, Foot Pat, Abdominal and Verticality). Differences in five SIAS motor scores were compared between the independent and non-independent walking groups. [Results] There was statistically significant difference between the groups in terms of Verticality among the 5 SIAS items used in the present research. Verticality of SIAS score of 1 was the cut-off value for distinguishing walking independence. [Conclusion] Verticality of SIAS may be a marker of potential walking independence that can be used in rehabilitation plans using walking-assist robots in patients with stroke.

**Key words:** Stroke, Robot training, Verticality

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### INTRODUCTION

Continuing advances in medical technology have decreased the number of deaths due to stroke. However, stroke is the second most common cause of nursing care home admissions in Japan<sup>1)</sup>, and approximately 80% of survivors feel that they have not completely recovered<sup>2)</sup>. Among the sequelae of stroke, gait disability is one of the major reasons that lead to decreased activities of daily living (ADLs).

Various gait-assist robots have been developed recently, among which rehabilitation robots have been recommended for use in gait training in hemiparetic stroke patients<sup>3, 4)</sup>. The Gait Exercise Assist Robot (GEAR), which was developed by Toyota Motor Corporation and Fujita Health University, is a walking-assist robot equipped with the following facilities: 1) a knee-ankle-foot robot, 2) low-floor treadmill, 3) safety suspension device, 4) monitor for patient use, and 5) control panel (Fig. 1). The system first determines the gait cycle from a pressure sensor located a sole of foot and the knee joint angle, and then executes flexion and extension of the knee joint at the appropriate timing. The control panel regulates torque for assisted knee extension as well as the force for assisted swing-out of the paralyzed lower limb, with robot weight support. By gradually reducing the level of assistance according to the patient's walking ability, the patient's effort is constantly maximized<sup>5)</sup>.

GEAR has been shown to have positive effects in stroke patients. Previous studies have reported that gait training using GEAR may be more effective than other training systems in patients with subacute and chronic stroke, and may facilitate early improvement in gait independence<sup>5-10)</sup>.

\*Corresponding author. Keita Aimoto (E-mail: aimoto@ncgg.go.jp)

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**Fig. 1.** The Gait Exercise Assist Robot (GEAR).

In our experience using GEAR with patients who were in convalescent rehabilitation and could not walk independently, we found that rehabilitation including GEAR training enabled independent walking. However, GEAR training cannot achieve walking independence in all patients, some of whom may never be able to walk independently. As far as we know, no studies have reported the initial factors associated with independent walking recovery by GEAR training. The purpose of the present research was to clarify the factors associated with achievement of independent walking in stroke patients following rehabilitation training using GEAR as a pilot study.

## **PARTICIPANTS AND METHODS**

We recruited 16 stroke patients as the participants of the study (age,  $67 \pm 13$  years; female,  $n=9$ ). The inclusion criteria were as follows: 1) hemiplegia, 2) inability to walk independently with a cane and ankle foot orthosis, and 3) hospitalized in a comprehensive rehabilitation ward. The exclusion criteria were as follows: 1) significant higher brain dysfunction, 2) bone or joint disease, or cardiac disease, that limits walking, and 3) inadequately controlled hypertension (resting systolic blood pressure at rest  $\geq 160$  mmHg, diastolic blood pressure  $\geq 100$  mmHg). The ethics committee of the National Center for Geriatrics and Gerontology approved this research (No. 859). Written informed consent was obtained from each participant or from the participant's family prior to participation.

GEAR training was conducted for 40 minutes per day, 3–5 times per week. The training duration was at least 4 weeks, and the maximum training duration was 12 weeks. Each participant received physical therapy including GEAR training, occupational therapy, and speech therapy. Their maximum total training time was 3 hours per day, 7 days per week. The training intensity was determined by medical doctors and therapists.

The main outcome was whether or not they needed assistance in walking 10 m. The participants were permitted to use a cane and ankle foot orthosis during the test.

All participants underwent baseline evaluation of the motor items in the Stroke Impairment Assessment Set (SIAS) prior to GEAR training. SIAS is simple and it is widely used in Japan for the evaluation of stroke patients. The SIAS comprises 22 motor and sensory evaluation items, of which Hip Flexion, Knee Extension, Foot Pat, Abdominal and Verticality of SIAS were evaluated in the present study. The score range for lower limb items (Hip Flexion, Knee Extension, Foot Pat) was 0–5, and those for trunk items (Abdominal and Verticality) was 0–3. Values for these five items were then entered into the personal computer dedicated to GEAR each time the participant completed GEAR training. It would therefore be useful if these GEAR standard database items could predict walking independence by GEAR training.

At the end of the training, the participants underwent the 10 m walking test and were divided into the supervision group (able to walk 10 m unassisted) and assistance group (required assistance to walk 10 m) accordingly. SIAS motor function score of at the start point of training was compared between the groups using Wilcoxon rank sum test. Receiver-operating characteristic (ROC) curve analysis was performed to identify cut-off values for factors significantly associated with ability to walk independently. The cut-off value was chosen that maximized the sum of sensitivity and specificity. All statistical analyses were performed using SPSS Ver 24.0 (IBM Japan, Tokyo, Japan) and the level of statistical significance was set to 5%.

## RESULTS

Table 1 lists the characteristics of the two groups. There were 7 people in the assistance group and 9 people in the supervision group. The SIAS scores for each group are listed in Table 2. Verticality of SIAS score was significantly higher in the supervision group than in the assistance group. ROC curve analysis revealed that the cut-off value predictive of walking independence was a score of 1 for Verticality of SIAS. Sensitivity was 0.89 and specificity was 0.57 for a score of 1 of Verticality of SIAS (Fig. 2).

## DISCUSSION

We investigated the factors related to acquisition of independent walking following GEAR training, and found that differences in the supervision and assistance of patients' walking ability may be related to Verticality of SIAS. Few previous studies have reported the effects of gait training robot training on walking recovery after stroke, although some have investigated recovery of walking ability without such training.

Dallas et al. performed a prospective evaluation of early test scores as predictors of ambulation and motor outcome at 6 months after stroke occurrence<sup>11</sup>. They concluded that early-stage TCT (Trunk Control Test) score was a predictor of independent walking ability and motor functional outcome at 6 months post-stroke. Martins et al. evaluated the relation between trunk function and other evaluation metrics such as National Institutes of Health Stroke Scale (NIHSS) and modified Ranking Scale (mRS) in stroke patients. Higher NIHSS and mRS scores at hospital discharge increased the risk of unsatisfactory trunk control at 90 days after stroke<sup>12</sup>. The systematic review of Preston et al. reported the following predictors of independent walking at 3 months in patients who were nonambulatory early after stroke: younger age, good leg strength, no neglect, and good sitting and so on<sup>13</sup>. The review of Selves concluded that trunk control and lower limb motor control were the best predictors of gait recovery<sup>14</sup>. These research has suggested that ADL scales and measures of trunk function such as TCT and sitting were predictors of independent walking after stroke. However, the level of impairment in the participants included in these studies ranged from mild to severe. Therefore, the factors associated with recovery related to walking in severe stroke patients have not been clearly identified.

Several previous reports have studied walking independence specifically in severely paralyzed patients. Kollen et al. identified age and BI as being related to independence in walking<sup>15</sup>. The participants were 101 first-ever ischaemic middle cerebral artery stroke patients who were not able to walk at onset, all of whom had marked hemiplegia. Seventy-two consecutive patients with a first attack of stroke and severe hemiplegia were included in Hirano's research. They retrospectively

**Table 1.** Characteristics of the supervision and assistance groups at the end of the Gait Exercise Assist Robot (GEAR) training

	Supervision n=9	Assistance n=7
Age (years)	63 ± 13	73 ± 10
Female, n	4	4
Affected side: left, n	3	4
Days from stroke (days)	76 ± 23	57 ± 19
Training duration (weeks)	8 ± 3	9 ± 3

Supervision group: able to walk 10 m unassisted. Assistance group: required assistance to walk 10 m.

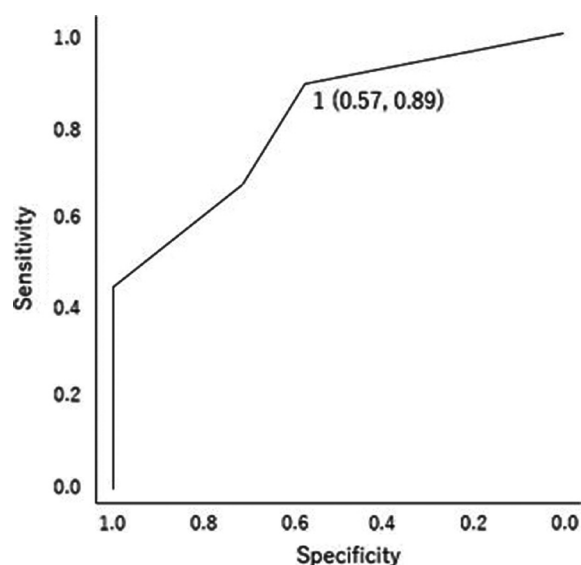
Data are presented as the mean ± standard deviation.

**Table 2.** Comparison of Stroke Impairment Assessment Set (SIAS) scores (5 items) used in the present study between the supervision and assistance groups

	Supervision	Assistance
Hip flexion	1 (0–3)	0 (0–1)
Knee extension	1 (0–3)	0 (0–1)
Foot pat	0 (0–3)	0 (0–0)
Abdominal	1 (0–3)	0 (0–2)
Verticality*	2 (0–3)	0 (0–2)

Data are presented as the median (range).

\*p<0.05; significant differences (Wilcoxon rank sum test).



**Fig. 2.** ROC curve for verticality of SIAS. Sensitivity was 0.89, specificity was 0.57, and area under the curve was 0.81. ROC: Receiver-operating characteristic; SIAS: Stroke Impairment Assessment Set.

evaluated background factors (age, gender, time from stroke onset, paresis side, and stroke type) and collected neurological and physical parameters at the time of admission (modified NIHSS, Mini-Mental State Examination, trunk control test [TCT], and the knee extension strength/body weight ratio on the unaffected side [KES/BW-US]). They found a significant difference between the independent walking and dependent groups in terms of age, TCT score, and KES/BW-US<sup>16</sup>. BI and TCT have been used as predictors of walking independence in severe stroke patients after stroke; however, they have not been employed in sufficient previous studies of severe stroke patients to provide a consistent view of the situation.

We extracted Verticality of SIAS related to trunk function as a predictor of independent walking. Some researchers have extracted indicators of trunk function such as TCT, which comprises four items: roll to the weak side; roll to the strong side; sit up from lying down; and sit in a balanced position on the edge of the bed, with the feet off the ground<sup>17</sup>). Verticality of SIAS was obtained in the sitting position and scored as follows: 0) unable to sit up; 1) lateral postural abnormality; 2) lateral postural abnormality, but can be corrected and maintained to almost vertical position by instruction; and 3) normal. Verticality of SIAS is similar to the TCT test because the TCT test includes balance in the sitting position.

Among the disorders of sitting balance, pusher behaviour is a postural control disorder characterized by the affected person actively pushing away from the nonparetic side and resisting passive correction with a tendency to fall toward the paralyzed side<sup>18</sup>). Danells et al. indicated that motor recovery and functional abilities at 3 months post-onset were significantly lower among pushers compared with non-pushers<sup>19</sup>). Because pusher behaviour is based on a postural orientation disorder, it is related to trunk control, and affects walking as well as sitting. Some of the present participants had abnormalities of sitting posture (Verticality of SIAS <3) such as pusher behavior.

Most of these previous studies have indicated the importance of ability to control the trunk for recovery of walking ability, which is in agreement with the present results. Recovery by walking training using GEAR is based on facilitation of motor learning, the same as conventional walking training in stroke patients. Therefore, factors predictive of independent walking may be similar between gait training using GEAR and normal walking training.

Although conducted as an exploratory study, our research has some limitations. First, the number of participants is small, and the study was conducted at a single institution. We will continue to accumulate participants and conduct multivariate analysis in future work. Second, the items used for evaluation was limited to those in SIAS. However, SIAS is simple and it is widely used in Japan for the evaluation of stroke patients, and it would therefore be useful if these items could predict walking independence by GEAR training. Third, we did not check all of the SIAS items, but investigated only the items used in the database provided on the computer dedicated to GEAR. It is unknown whether other SIAS items might be more strongly related to walking independence.

In conclusion, we investigated differences between stroke patients who could not walk independently and those who were able to walk after GEAR training. There was a statistically significant difference in Verticality of SIAS between these two groups, which suggests that ability to control the trunk may be useful in predicting prognosis in stroke patients. In patients with a Verticality of SIAS score of 0, training to reduce the amount of assistance for basic activities such as rolling and transfer between a wheelchair and a bed should be selected, rather than walking training with GEAR.

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## Conflict of interest

All authors declare that there are no conflicts of interest.

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