

# Comparisons between Locomat and Walkbot robotic gait training regarding balance and lower extremity function among non-ambulatory chronic acquired brain injury survivors

Hoo Young Lee, MD<sup>a,b,c,d</sup>, Jung Hyun Park, MD, PhD<sup>c,e</sup>, Tae-Woo Kim, MD<sup>a,b,\*</sup> 

## Abstract

Lower limb rehabilitation exoskeleton robots connect with the human body in a wearable way and control the movement of joints in the gait rehabilitation process. Among treadmill-based lower limb rehabilitation exoskeleton robots, Lokomat (Hocoma AG, Volketswil, Switzerland) has 4 actuated joints for bilateral hips and knees whereas Walkbot (P&S Mechanics, Seoul, Korea) has 6 bilateral actuated joints for bilateral hips, knees, and ankles. Lokomat and Walkbot robotic gait training systems have not been directly compared previously. The present study aimed to directly compare Lokomat and Walkbot robots in non-ambulatory chronic patients with acquired brain injury (ABI).

The authors conducted a single-center, retrospective, cross-sectional study of 62 subjects with ABI who were admitted to the rehabilitation hospital. Patients were divided into 2 groups: Lokomat (n = 28) and Walkbot (n = 34). Patients were subjected to robot-assisted gait training (RAGT) combined with conventional physical therapy for a total of 14 (8–36) median (interquartile range) sessions. Baseline characteristics, including age, sex, lag time post-injury, ABI type, paralysis type, intervention sessions, lower extremity strength, spasticity, and cognitive function were assessed. Functional ambulation category (FAC) and Berg balance scale (BBS) were used for outcome measures.

There were no significant differences in baseline characteristics between the groups. Baseline FAC score was 1 (0–2) in Lokomat and 1 (0–1) in Walkbot group. After the intervention, FAC scores improved significantly to 2 (1–3) in both groups ( $P < .05$ ). Lokomat and Walkbot groups showed significantly enhanced BBS from 5 (2.75–24.25) and 15 (4–26.5) to 15 (4–26.5) and 22 (12–40), respectively ( $P < .05$ ). Degree of improvements in both group were not significantly different with regard to balance ( $P = .56$ ) and ambulatory ability ( $P = .74$ ).

This study indicates that both Locomat and Walkbot robotic gait training combined with conventional gait-oriented physiotherapy are promising intervention for gait rehabilitation in patients with chronic stage of ABI who are not able to walk independently.

**Abbreviations:** ABI = acquired brain injury, FAC = functional ambulatory category, RAGT = robot-assisted gait training, RDGO = robot-driven gait orthosis, TBI = traumatic brain injury.

**Keywords:** brain injury, chronic, gait, rehabilitation, robotics, stroke

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The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

<sup>a</sup> TBI rehabilitation center, National Traffic Injury Rehabilitation Hospital, Gyeonggi-do, <sup>b</sup> Department of Rehabilitation Medicine, Seoul National University Hospital, Seoul University College of Medicine, <sup>c</sup> Department of Medicine, Yonsei University College of Medicine, Seoul, South Korea, <sup>d</sup> National Traffic Injury Rehabilitation Research Institute, National Traffic Injury Rehabilitation Hospital, Yangpyeong, South Korea, <sup>e</sup> Department of Rehabilitation Medicine, Gangnam Severance Hospital, Rehabilitation Institute of Neuromuscular Disease, Yonsei University College of Medicine, Seoul, Republic of Korea.

\* Correspondence: Tae-Woo Kim, TBI rehabilitation center, National Traffic Injury Rehabilitation Hospital, 260, Jungang-ro, Dogok-ri, Yangpyeong-eup, Yangpyeong-gun, Gyeonggi-do, 12564, Republic of Korea, Department of Rehabilitation Medicine, Seoul National University Hospital, Seoul University College of Medicine, Seoul, Republic of Korea (e-mail: taewookimmd@gmail.com, drcadaver@naver.com).

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## 1. Introduction

Acquired brain injury (ABI) induces significant levels of disability resulting in long-term functional limitations.<sup>[1,2]</sup> Improved walking ability post-ABI, is one of the most important goals of rehabilitation to enhance functional activity, social participation, and perceived quality of life.<sup>[3]</sup> Although the majority of stroke patients learn to walk independently by 6 months post-ABI, gait and balance issues persist through the chronic stages of the condition, with a significant impact on patients' quality of life.<sup>[4-6]</sup>

Factors that lead to gait impairment after ABI include decreased cardiorespiratory fitness, decreased muscle strength and motor control, abnormal muscle tone, abnormal sensation, and cognitive and perceptual dysfunction.<sup>[7]</sup> Patients receiving electromechanical-assisted gait training in combination with physiotherapy after ABI are more likely to walk independently than individuals who undergo gait training without these devices.<sup>[8,9]</sup> However, training individuals at challenging gait speeds and body weight support for an extended time is physically demanding on physical therapists. Therapist burnout could limit training duration as much as patient fatigue. Further, according to the modern concept of motor learning, individuals with ABI should practice high-intensity and diverse tasks repeatedly and receive accurate visual feedback of their performance.<sup>[10]</sup>

Hence, the first robot-driven gait orthosis (RDGO), the Lokomat, was developed by Hocoma in 1999. The Lokomat (Hocoma AG, Volketswil, Switzerland) provides variable propulsive forces according to a pre-programmed gait pattern.<sup>[11]</sup> The Lokomat contains 2 bilateral programmable and actuated robotic joints attached to the patients' legs to facilitate hip and knee movements as they walk on a treadmill. Passive foot lifters support ankle dorsiflexion during the swing phase. The leg motion can be controlled with highly repeated and predefined hip and knee joint trajectories based on a conventional position control strategy. A similar lower limb rehabilitation exoskeleton robots known as Walkbot (P&S Mechanics, Seoul, Republic of Korea) also enhance ambulation by providing adjusted body-weight-bearing control and real-time visual biofeedback for torque and stiffness, and kinematics for the hip, knee, and ankle joints. The device consists of a suspension harness for body

weight support, a motorized treadmill, and an actuator controlled exoskeleton.<sup>[12]</sup>

A growing body of evidence suggests that patients in the first 3 months after stroke and those unable to walk appear to benefit most from robot-assisted gait training (RAGT) in combination with physiotherapy.<sup>[8,13]</sup> Lokomotor training based on RAGT systems in patients with traumatic brain injury (TBI) improved the gait kinematics.<sup>[9,14]</sup> However, few studies investigated the impact on chronic non-ambulatory subjects after ABI.

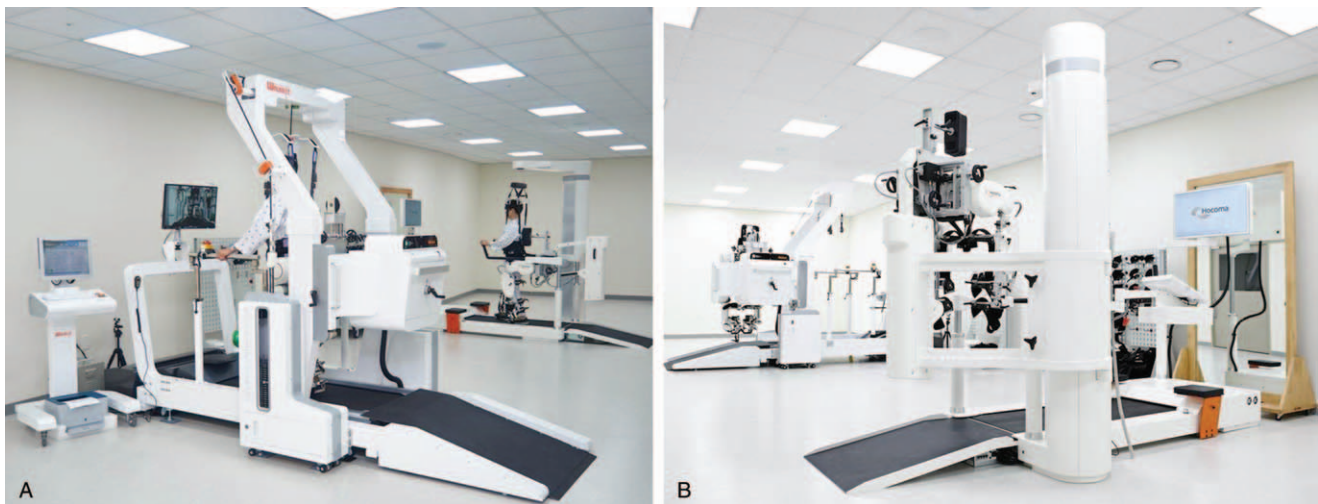
Numerous studies have focused on the effects of robotic technology versus conventional gait training on locomotor training.<sup>[7,8,13,14]</sup> However, the robots utilized in the previous studies were largely single type. Few studies investigated the comparative effects of different robotic gait training systems with regard to the mechanical characteristics. Therefore, the present study investigated the effects of RAGT modulated by Lokomat and Walkbot, both combined with conventional gait-oriented physiotherapy on the walking abilities of chronic non-ambulatory patients with ABI. Further, the study investigated whether the improved walking ability following Lokomat robotic gait training was distinct from the enhancement achieved using Walkbot in subjects with chronic and severe gait deficits after ABI.

## 2. Methods

The study was a retrospective, cross-sectional study of patients who experienced ABI and were admitted to a comprehensive rehabilitation hospital in the Republic of Korea over a 3-year period between October 1, 2014 and July 31, 2017.

All the subjects were provided with RAGT for median (interquartile ranges [IQR]) 14 (10–20) sessions held on 2 to 5 days each week along with conventional physiotherapy 5 days a week. Each RAGT session lasted a maximum duration of 30 minutes of effective RAGT and another 30 minutes were allocated to mounting, dismounting, and adjustment of the system.

The Lokomat and Walkbot (Fig. 1) systems utilized in this study are 2 robotic exoskeletons combined with a harness-supported body weight system. They combine fully programma-



**Figure 1.** Treadmill-based lower limb rehabilitation exoskeleton robots: (A) Lokomat, (B) Walkbot systems.

ble technologies, including optimal loading, adequate sensory input, optimal limb movement, interlimb coordination, task-specific locomotion, and real-time torque and kinematic biofeedback based on visual and haptic signals. The force, body weight support, and speed in both types of exoskeletal robots can be adjusted to assist even severely handicapped patients during exercise in a challenging environment. Postural control, propulsion, coordination, stepping, and walking speed were based significantly on motor learning concepts and RAGT standards ranging from simple to the complex, and progressing from easy to difficult levels, while all movements remained as close as possible to the final desired movement.<sup>[15,16]</sup>

The Lokomat and Walkbot training parameters were collected at every session to analyze the participants' progression.

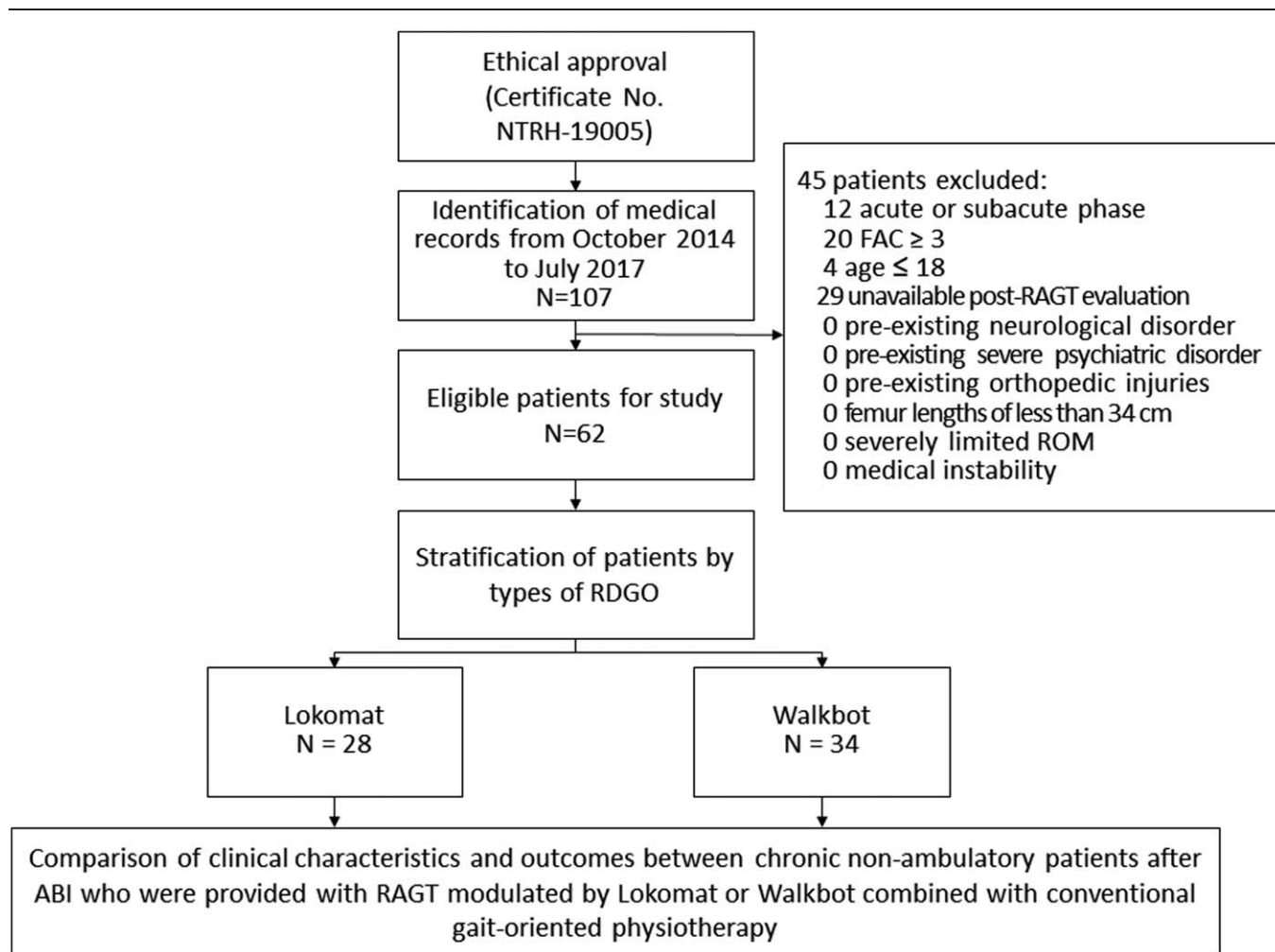
We retrospectively evaluated raw data obtained from the Clinical Data Warehouse (CDW) in the hospital, including a database of electronic medical records obtained from both inpatients and outpatients for real-time clinical analysis. The CDW contains almost all the medical records, including every field note of the medical staff (admission and discharge notes, progress reports, and nursing data), patient information data, and records obtained (insurance, diagnostic codes, age, sex, and vital signs), test results reported (laboratory tests, functional

assessments, and imaging studies), and treatment modalities used (medications, therapies, and medical procedures). The data were de-identified and transferred to the research team. Consequently, the patient's permission was not required.

The inclusion criteria were: chronic hemiplegia or quadriplegia with significant gait deficits (functional ambulatory category [FAC] < 3) caused by a first-ever ABI, duration of disease longer than 3 months, cognitive capability to comply with the protocol, and age higher than 18 years. Exclusion criteria were: patients in acute or subacute phases after ABI, chronic neurodegenerative pathology, FAC ≥ 3, pre-existing neurological disorder, severe psychiatric disorder, or orthopedic injuries before the brain injury, femur lengths measuring < 34 cm, severely limited range of joint motion involving lower extremity, and medical instability (Fig. 2).

This study was approved by the Institutional Review Board of National Traffic Injury Rehabilitation Hospital (No. NTRH-19005). It was conducted in accordance with the Declaration of Helsinki.

Clinical parameters of strength, spasticity, and cognitive function were used to compare baseline impairment between the groups. Strength was determined via manual muscle testing of bilateral ankle dorsal and plantar flexors, knee flexors and



**Figure 2.** Patient recruitment and retrospective study design. FAC=functional ambulation category, RAGT=robot-assisted gait training, RDGO=robot-driven gait orthosis; ROM=range of motion.

**Table 1**  
**Patients' demographic and baseline characteristics.**

	Lokomat group (n=28)	Walkbot group (n=34)	P-value*
Demographics			
Age, yrs, median (IQR)	55.50 (32.50–60.75)	56 (43.75–64.75)	.35
Time to acquired brain injury, mo	8 (4–10)	6 (3–14)	.90
Male (%)	75	71	.70
Etiology (n [%])			.25
Traumatic brain injury	7 (25)	8 (24)	
Vascular	20 (71)	21 (62)	
Anoxia	1 (4)	2 (6)	
Other	0 (0)	3 (9)	
Hemiplegia (%)	75	71	.70
Number of sessions	12 (10–20)	16 (10–20)	.37
Baseline impairments			
Muscle testing, sum modified Ashworth scale	48.5 (38.5–54.75)	50.5 (46–58)	.16
Mini-Mental Status Examination in the Korean Version of the CERAD assessment packet	1 (0–2)	1 (0–2)	.62
	20 (12–26.75)	25 (15–28)	.14

Note. Data are reported as n (%) or median (interquartile range).

\* One-tailed significance:  $P < .05$ .

extensors, and hip flexors, extensors, adductors, and abductors, based on manual muscle testing (MMT) scores ranging from 0 to 80.<sup>[17]</sup> Spasticity was assessed using the most severe values of modified Ashworth scale (MAS) scores of ankle plantar flexors, knee flexors and extensors, and hip flexors, extensors, and adductors. Cognitive function was evaluated via Mini-Mental Status Examination based on the Korean Version of the CERAD Assessment Packet (MMSE-KC).

The outcomes of locomotor function were divided into balance, level of gait and overall physical function, and evaluated within 1 month before and after the RAGT combined with physiotherapy. Balance was evaluated with the postural assessment scale for stroke patients (PASS) and Berg balance scale (BBS). PASS comprises 12 items for the evaluation of balance: 5 items to determine the posture (static PASS) and 7 items to evaluate changes in posture (dynamic PASS). BBS was used for the comprehensive evaluation of patients' sitting balance, standing balance, and walking ability. BBS includes 14 common tasks of ability to maintain position or movements of increasing difficulty by decreasing the base of support from seated to standing and single-limb support. The FAC scores were utilized as outcome measures of gait functional status. The overall physical function was assessed using total, transfer, and mobility scores of the Korean version of modified Barthel Index (K-MBI).

### 2.1. Statistical analysis

Statistical analysis included a descriptive analysis of general characteristics using the median and IQR. For comparison of demographic data obtained from both groups, independent *t* tests were used for continuous variables, and Mann–Whitney *U* tests for categorical variables.

The clinical parameters before (T0) and after (T1) robotic training were compared using a paired *t* test for continuous data and a Wilcoxon signed-rank test for non-continuous data.

A further comparative analysis of pretraining and posttraining changes between the 2 groups was performed. Independent *t* tests were used to analyze continuous variables and Mann–Whitney *U*

tests were used for categorical variables.  $P < .05$  was considered statistically significant. The analysis was performed using SAS version 9.4 (SAS institute, Cary, NC).

## 3. Results

### 3.1. Patients' clinical demographics

Among the total of 1371 inpatients monitored during the 3-year observation period, 44.7% (n=613) were primarily diagnosed with ABI. Of those patients, 17.5% (n=107) were exposed to RAGT and conventional gait-oriented physiotherapy. After applying the exclusion criteria, 57.9% (n=62) referred for further analysis (Fig. 2).

Table 1 lists the demographic characteristics and measures of impairment (i.e., strength, spasticity, and cognitive function) of patients who were subjected to RAGT. No statistically significant differences in these variables were detected before training. Specifically, there were no differences in total or individual scores of muscle strength involving the paretic lower limb or the nonparetic limb. MAS values were not different at any joint (plantar flexor scores listed in Table 1).

### 3.2. Effects of RAGT combined with conventional physiotherapy on balance, and ambulatory and overall physical function

Changes in outcome measures reflecting balance and gait function in Lokomat and Walkbot groups are summarized in Table 2. After the training, the walking ability of the Lokomat and the Walkbot groups was enhanced as the FAC was significantly improved. The FAC (median [IQR]) was at baseline 1 (0–2) in the Lokomat group and 1 (0–1) in the Walkbot group, and increased significantly to 2 (1–3) in both groups after training with 95% confidence interval. Paired *t* test and Wilcoxon signed-rank tests showed a significant effect of intervention before and after training based on PASS, BBS, FAC, and total, transfer, and mobility scores of K-MBI.

**Table 2**  
Improvement in balance, gait, and overall physical function.

Clinical outcomes	Lokomat (n=28)		P-value	Walkbot (n=34)		P-value
	T0	T1		T0	T1	
Postural assessment scale for stroke	24 (15.5–28.25)	29.5 (19.75–31.25)	.02*	21 (13–24.75)	28 (21.5–32)	.00†
Berg balance scale	5 (2.75–24.25)	22.5 (5–35.5)	.00†	15 (4–26.5)	22 (12–40)	.00†
Functional ambulation category	1 (0–2)	2 (1–3)	.00†	1 (0–1)	2 (1–3)	.00†
Korean version of modified Barthel Index						
Total	35 (23–45)	50 (27–61)	.00†	44 (26–56)	59 (34.5–67)	.00†
Transfer	8 (3–8)	8 (8–12)	.01†	8 (3–9)	8 (8–12)	.00†
Mobility	0 (0–2.5)	3 (0–8)	.01†	0 (0–4.25)	3 (0–8)	.00†

Note. Data are reported as median (interquartile range).

\* Two-tailed significance:  $P < .05$ .

† Two-tailed significance:  $P < .01$ .

### 3.3. Comparison of pretraining and posttraining changes between Lokomat and Walkbot groups

The extent of interaction did not differ significantly in terms of BBS, FAC, and total, transfer, and mobility scores of K-MBI between the 2 groups. Based on PASS, the Walkbot group showed significantly larger interaction than the Lokomat group (Table 3).

## 4. Discussion

In the last decade, a growing number of robots with a diverse range of mechanical structures have been used clinically for locomotor training of patients with ABI. However, the effectiveness of RAGT is still disputed, especially in chronic non-ambulatory patients.

It is widely recognized that spontaneous behavioral recovery mostly occurs within the first 3 months after ABI onset and patients in the first 3 months after ABI may derive the maximum benefit from RAGT. Nevertheless, different patterns of recovery may emerge depending on several complex factors, and therefore, neuroplasticity associated with functional recovery may also be apparent in the chronic phase.<sup>[8,13]</sup> In patients with chronic and severe gait deficits after ABI, practice and repetitive movements are a prerequisite for improved motor performance and motor learning.<sup>[18]</sup> Individuals with severe deficit exhibit poor function and enter gait training program in the explicit learning phase, thus requiring extensive cortical processing to gain volitional control and internal and external proficiency.<sup>[19,20]</sup>

Previous studies demonstrated that survivors of chronic ambulatory ABI continue to improve in motor recovery and functional ability after intensive over-ground or robotic-assisted locomotor training.<sup>[7,17]</sup> No significant differences in effectiveness were found between RAGT and conventional therapy in patients with impaired gait.<sup>[16,21,22]</sup>

Few studies investigated the effects of RAGT on patients with chronic non-ambulatory ABI. Previous studies reported that RAGT was effective in improving balance, motor skills, and gait performance based on BBS, modified functional reach test, motoricity index, and FAC scores.<sup>[18,23,24]</sup>

In the current study, we hypothesized that non-ambulatory patients in the chronic phase of ABI who underwent RAGT with Lokomat or Walkbot in combination with physiotherapy show improved gait function regardless of the type of robotic system. Thus, we found significant and analogous recoveries in balance, walking ability, and overall physical function in the 2 groups. An in-depth review of our results demonstrates that RAGT combined with conventional gait-oriented physiotherapy did not shift chronic non-ambulatory patients to ambulatory subjects, and the overall physical function was severely dependent based on the K-MBI, regardless of the types of RDGO. Granger et al<sup>[25]</sup> suggested 60/100 as the cut-off between marked dependence and higher levels of independence. However, RAGT modulated by both Lokomat or Walkbot combined with conventional physiotherapy significantly reduced the degree of continued support derived from a single person who assisted with weight bearing and balance to a single person providing continuous or intermittent support to facilitate balance and coordination.

Balance is a key element contributing to optimal gait function in patients with ABI. In particular, sitting postural control is an important prerequisite for independent daily activities in the stages prior to recovery of ambulatory function.<sup>[26–29]</sup> A cut-off BBS score 12 and a cut-off PASS score 12.6 predicted non-ambulators to regain unassisted ambulation.<sup>[28,29]</sup> A previous systemic review that investigated the relationship between RAGT and balance in stroke patients reported significant improvements in balance scores after RAGT.<sup>[30]</sup> Until now, no clear evidence supported a relationship between RAGT and balance function in chronic patients with a poor function after ABI. In this study, both Lokomat- and Walkbot-assisted gait training programs

**Table 3**  
Pretraining versus posttraining changes between the 2 groups.

Clinical outcomes	Postural assessment scale for stroke	Berg balance scale	Functional ambulation category	Korean version of modified Barthel Index		
				Total	Transfer	Mobility
P-value	.04*	0.56	0.74	0.26	0.77	0.68

\* One-tailed significance:  $P < .05$ .

significantly increased the PASS, BBS, and mobility domains of K-MBI scores, and consequently, the FAC score in chronic non-ambulatory patients after ABL.

Until now, no clear evidence demonstrated the type of rehabilitation robot associated with optimal outcome in patients with ABL. A recent Cochrane review found no statistically significant effect in restoring independent walking ability among participants treated with exoskeletal devices.<sup>[8]</sup> In this study also, the outcome measurement revealed that RAGT and physiotherapy modulated by Lokomat or Walkbot contributed to enhanced balance and walking ability; however, no significant device-dependent differences were found. Lokomat is the first gait orthosis that facilitated walking in gait-impaired patients on the treadmill, by coordinating hip and knee joints, and in case of the ankle joint, via ankle-foot orthosis with a plantar flexion stop spring.<sup>[31]</sup> The Walkbot system is the first gait orthosis that coordinates hip-knee-ankle joints via enhanced natural gait training for foot drop and toe drag via control of ankle dorsiflexion and plantar flexion.<sup>[32]</sup> We suggest that repetitive locomotor training with RAGT modulated by Lokomat and Walkbot, combined with conventional physiotherapy may lead to restoration of motor learning and performance, result in improved balance function.

The Lokomat-assisted gait training is effective in similarly improving the balance and walking ability when combined with physiotherapy compared with Walkbot-assisted gait training with physiotherapy in chronic non-ambulatory patients with ABL. Most importantly, this study provides the first clinical evidence demonstrating that the therapeutic effects of combined RAGT and physiotherapy assisted with exoskeletal robotics modulated via 3 actuated joints for hip, knee, and ankle on the recovery of balance, walking ability, and overall physical function were comparable to RAGT modulated by RDGO with 2 actuated joints for hip and knee combined with physiotherapy.

The present study has some limitations. First, this was a retrospective study conducted in a single center. Therefore, selection bias could be present. Other study limitations include the lack of randomization and the limited sample size. Although all patients participated in regular inpatient rehabilitation during the study, including physical, occupational, and speech therapies, and psychosocial sessions, the clinical continuum of care was similar across all study participants. Further, because no follow-up data are included, it is not possible to establish whether the results persisted with time. Therefore, the results obtained should be considered as preliminary. Also, the study did not compare the robotic training groups to control group that received conventional gait training, and thus it is difficult to determine definitely that Lokomat or Walkbot-assisted gait training with physiotherapy was the cause of the observed changes. Future research should make these isolated comparisons to increase insight into the effects of combined RAGT and physiotherapy on locomotor recovery in chronic, non-ambulatory patients after ABL. Moreover, further large-scale randomized trials with follow-up are needed to corroborate our data.

This study adds to sparse literature demonstrating the role of rehabilitation robotics in locomotor training of chronic, non-ambulatory patients after ABL. RAGT with Lokomat and Walkbot combined with conventional gait physiotherapy may contribute to significant reduction in assisted walking by significantly improving the balance function in chronic non-ambulatory ABI patients.

## Author contributions

**Conceptualization:** Hoo Young Lee, Tae-Woo Kim.

**Data curation:** Hoo Young Lee, Jung Hyun Park.

**Formal analysis:** Hoo Young Lee, Tae-Woo Kim, Jung Hyun Park.

**Funding acquisition:** Tae-Woo Kim.

**Methodology:** Hoo Young Lee, Jung Hyun Park.

**Project administration:** Tae-Woo Kim.

**Software:** Hoo Young Lee.

**Supervision:** Tae-Woo Kim, Jung Hyun Park.

**Validation:** Hoo Young Lee.

**Visualization:** Hoo Young Lee.

**Writing – original draft:** Hoo Young Lee.

**Writing – review & editing:** Hoo Young Lee, Tae-Woo Kim.

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