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Case Study

Long-term sustained effect of gait training using a hybrid assistive limb on gait stability via prevention of knee collapse in a patient with cerebral palsy: a case report

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Abstract. [Purpose] The hybrid assistive limb was developed to improve the kinematics and muscle activity in patients with neurological and orthopedic conditions. The purpose of the present study was to examine the long-term sustained effect of gait training using a hybrid assistive limb on gait stability, kinematics, and muscle activity by preventing knee collapse in a patient with cerebral palsy. [Participant and Methods] A 17 year-old male with cerebral palsy performed gait training with a hybrid assistive limb 12 times in 4 weeks. After completion of 12 sessions of hybrid assistive limb training, monthly follow-up was conducted for 8 months. The improvement was assessed on the basis of joint angle and muscle activity during gait. [Results] The degree of knee collapse observed at baseline was improved at 8-month follow-up. Regarding muscle activity, electromyography revealed increased activation of the vastus lateralis at 8-month follow-up. Moreover, the hip and knee angles were expanded during gait. In particular, the knee extension angle at heel contact was increased at 8 months after follow-up. [Conclusion] Gait training with a hybrid assistive limb provided improvement of gait stability such as kinematics and muscle activity in a patient with cerebral palsy. The improved gait stability through prevention of knee collapse achieved with hybrid assistive limb training sustained for 8 months.

Key words: Hybrid Assistive Limb (HAL), Cerebral palsy, Knee collapse

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INTRODUCTION

Cerebral palsy (CP) induces permanent motor disorders that are considered difficult to resolve. The most frequent motor disorder encountered in CP is spasticity (prevalent in 60% of children with CP)[1)]. Spasticity is closely related to gait ability,

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and decreased gait ability causes limitations of the activities of daily living. To improve gait ability, various robotic devices have been developed for rehabilitation training, and recent studies have reported the effect of gait training using robotic devices.

One representative robotic device used for gait training is the Lokomat (Hocoma Company, Volketswil, Switzerland). The Lokomat is a passive robotic gait intervention that involves setting the lower limb joint angle and gait speed at constant values during treadmill walking. However, gait training using the Lokomat reportedly conveys no advantage compared with conventional rehabilitation[2, 3].

Another recently developed wearable robotic device is hybrid assistive limb (HAL, Cyberdyne Inc., Tsukuba, Japan). A HAL is a hybrid control system composed of two subsystems: cybernic voluntary control and cybernic autonomous control[4]. A force-pressure sensor in the patient's shoes sends a signal that is used to detect the gait stance phase. Additionally, the muscle action potential is measured to determine the amount of torque and enable appropriate adjustments. A HAL has a function that enables the imitation of normal gait, it is considered that rehabilitation using a HAL helps improve voluntary muscle contraction. The difference between these two robotic assistive devices is that a HAL improves the users' voluntary muscle activity, whereas the Lokomat assists passively by creating a regular gait pattern. Several studies have reported that gait training using a HAL improved walking speed, step length, and gait endurance in patients with subacute stroke[5, 6]. Furthermore, a recent investigation demonstrated that training with a HAL after total knee arthroplasty improved knee joint function[7]. For patients with CP, a single gait training session with a HAL reportedly improves the single-leg support per gait cycle, and the hip and knee joint angles during gait[8]. However, in patients with CP, the long-term sustained effects of multiple training sessions with a HAL on gait stability, kinematics, and muscle activity remain uncertain.

The purpose of the present study was to examine the long-term sustained effect of gait training using a HAL on gait stability, kinematics, and muscle activity in a patient with CP.

PARTICIPANT AND METHODS

A 17 year-old male (height 152.1 cm, weight 54.6 kg) was diagnosed with intraventricular hemorrhage at birth. The patient had a motor function of level III in accordance with the Gross Motor Function Classification System[9]. A means of movement in activities of daily living was electric wheelchair, which was controlled by his hand. In the lower extremities, the patient's left side was more affected by spasticity than the right side. He was unable to walk without the assistance of a walker at the time of physical therapy, and the knee joint was flexed during gait.

Gait training using a HAL was conducted 12 times in 4 weeks in addition to conventional physical therapy by a trained physiotherapist. After 12 times HAL training finished, only conventional physical therapy which consisted of gait training and range of motion exercise, muscle strength exercise was continued once in a month. Gait examination was conducted until after 8-month follow-up every other month. A small-sized HAL (HAL-ML05-DSMJP) was used for gait training with a walker (All-In-One Walking Trainer, Repox A/S, Naestved Denmark) and cybernic voluntary control. The mobile suspension system harness of the walker provided safety in case the patient fell. To adjust the height of the handrail, a stretch pole (Tumble Forms, Sammons Preston, USA) was mounted on the walker. Each training session consisted of up to 20 minutes of walking using a HAL (Fig. 1).

Gait training using a HAL was approved by the Ibaraki Prefectural University of Health Sciences (approval number: 682), and the patient's family provided written informed consent for the intervention.

Kinematic data, such as joint angles and angular velocities, were acquired using a motion capture system (Vicon Nexus, Oxford Metrics, Oxford, UK) consisting of eight cameras (sampling rate: 100 Hz). Acquired marker coordinates were filtered by a Woltring quantic spline routine[10]. A widely used conventional marker set model (Plug-in Gait model, Oxford Metrics) was used to calculate the joint angles after the definition of segments. In addition, joint angles were differentiated in terms of time, allowing the angular velocity to be calculated.

$$anglular\ velocity = \frac{joint\ angle}{\Delta t}[deg/s]$$

Electromyography (EMG) of the vastus lateralis (VL) and semitendinosus (ST) was performed using a surface EMG device (Trigno Wireless Systems, Delsys Inc., MA, USA). These two muscles were chosen as the representative knee muscles mainly responsible for flexion and extension. The EMG signals were collected at a sampling rate of 2,000 Hz, and bandpass filtering of 20–450 Hz. Subsequently, an absolute EMG was integrated by time to calculate an integrated EMG (iEMG).

The kinematic data and EMG signals were processed in MATLAB R2016b (MathWorks Inc., Natick, MA, USA). To standardize the time of one gait cycle as 100%, all data was interpolated by the third spline.

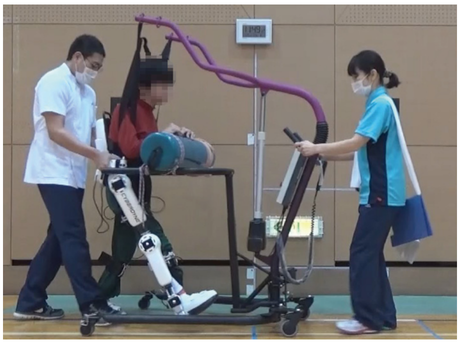

Fig. 1. Photograph of the gait training using a hybrid assistive limb.

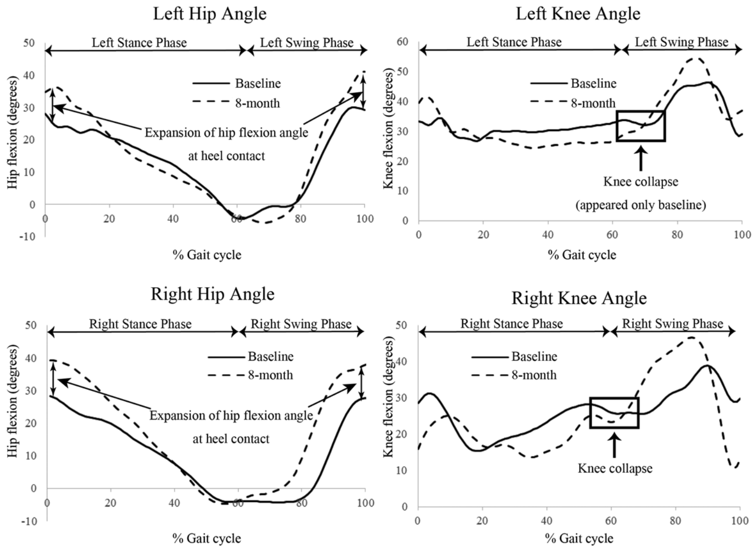

Fig. 2. Flexion and extension angles of the bilateral hip joints (left) and bilateral knee joints (right) at baseline and at 8-month follow-up.

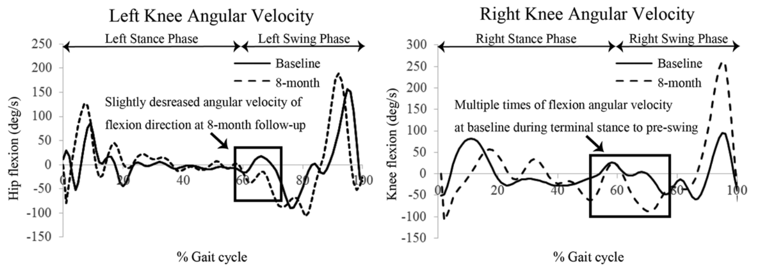

Fig. 3. Angular velocity of the left knee (left) and the right knee (right) at baseline and at 8-month follow-up.

One gait cycle was defined as the sequence of events from heel contact to ipsilateral heel contact.

These data were collected nine times for each month from beginning of HAL training until 8 months. The joint angles and angular velocities were compared at baseline versus at 8-month follow-up after training. Similarly, the iEMG values were compared at baseline versus at 8-month follow-up after training.

RESULTS

GMFCS level was III at 8-month follow-up and it was not improved comparing baseline with 8-month follow-up.

The joint angles at baseline and at 8-month follow-up are shown in Fig. 2. At around 60–70% of the gait cycle, the left knee angle was more extended at 8-month follow-up, while the knee angle at baseline was flexed at terminal stance; this flexed knee position denotes the knee collapsing due to insufficient body weight support. The right knee angle showed lengthy and multiple angle variations of collapse at terminal stance. Compared with baseline, the flexion angles of the bilateral hip joints at heel contact were increased by approximately 10° at 8-month follow-up. Similarly, the degrees of flexion and extension of the bilateral knee joint angles were obviously increased at 8-month follow-up.

The knee angular velocity is shown in Fig. 3. In the left knee, there was a slightly decreased angular velocity in the flexion (positive) direction at around 60–70% of the gait cycle. Rapid variation in flexion angular velocity at the stance phase may indicate knee collapse. In the right knee, change in flexion angular velocity was observed multiple times during the terminal stance phase at baseline compared with at 8-month follow-up.

The iEMG result of the left VL was extended after the terminal stance phase at 8-month follow-up compared with baseline (Fig. 4). The variation in the left ST iEMG after the stance phase was also elongated (Fig. 4). The right VL iEMG was significantly increased from the terminal stance to the initial swing phase when comparing baseline values with values at

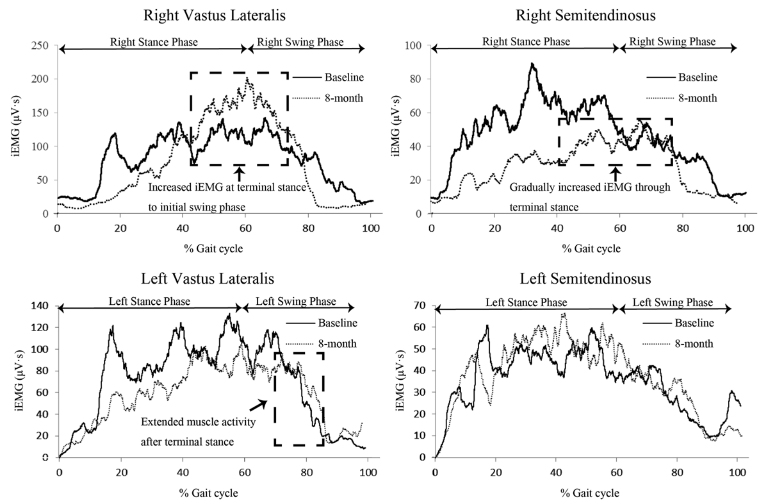

Fig. 4. Integrated electromyographic results of the bilateral vastus lateralis muscles and semitendinosus muscles at baseline and at 8-month follow-up.

8-month follow-up. The left ST iEMG was gradually increased through the terminal stance. In the right knee, the activation of ST was gradually increased, corresponding with the variation in knee flexion angle.

These joint angle and iEMG improvements were not observed at 1-month follow-up, but similar improvement at 8-month follow-up was observed at 4-month follow-up.

DISCUSSION

The present results confirmed that gait training with a HAL improved the long-term sustained gait stability, kinematics, and muscle activity in a patient with CP. This indicates that gait training using a HAL is a promising rehabilitation method for improving abnormal gait that involves knee collapse.

Knee collapse can be identified by measuring the knee joint angle. Furthermore, the angular acceleration was investigated in the present study to examine the knee collapse in more detail. At baseline, the abrupt changes in bilateral knee angular velocities toward the flexion direction at around 60–70% of the gait cycle suggest that knee collapse was occurring. The left knee angular velocity at 8-month follow-up was reduced compared with baseline, suggesting that the knee collapse was reduced, and that gait training with a HAL improved the gait. Regarding the right knee, flexion angular velocity was detected multiple times at baseline during the terminal stance to pre-swing phase. Multiple occurrences of knee collapse during one stance phase suggests that the gait is unstable. At 8-month follow-up, these multiple episodes of knee collapse changed into a single knee collapse. A decrease in the number of knee collapse episodes indicates that the HAL training improved gait stability.

EMG showed that the primary effect of HAL training was a sustained iEMG for the VL and the ST after the stance phase. During mid-stance to terminal stance, the knee reaches maximum flexion and then starts to extend due to quadriceps contraction[1)]. The reductions in knee collapse may be due to correlated and sustained activities of the VL and the ST immediately after the stance phase. In the present patient, consistency of ST activity and knee flexion angle was confirmed only in the right knee. Patients with CP who have increased activity of the medial hamstring muscles during the pre-swing stance reportedly have a tendency to walk with their knees more flexed during stance[11)]. The present results showing the consistency of ST activity and knee flexion angle suggest that muscle activity during gait became better able to control the knee joint movement. The reduction in knee collapse contributes to preventing the patient from falling down. Riad et al. reported that spastic hemiplegic CP involves a lesser degree of muscle work by the affected knee extensors compared with the noninvolved side during walking[12)]; the present VL iEMG result is congruent with this previous finding. Gait function is adversely affected by CP, and the principal purpose of rehabilitation is the acquisition of a stable gait to decrease the risk of falling down, which is important for activities of daily living.

The present investigations of the hip and knee joint angles showed that an extension angle appeared at the stance phase. These results indicate that the patient supported his body in the knee extension posture during the stance phase period. After HAL training, the increased right VL iEMG in the stance phase enabled the patient to improve the knee posture in the stance phase. Additionally, the maximum flexion angles of the hip and knee joints were increased in the swing phase. The increased hip flexion angle is thought to be caused by the improved ability to support bodyweight in the knee extension posture.

As for the reason that joint angle and iEMG were not improved at 1-month follow-up, it is considered that fatigue by the intervention training was remaining. However, fatigue was recovered at 4-month follow-up, these improvements may have been appearing.

In this study, the important finding is improvement of VL and ST muscle activity contributed prevention of knee collapse. Its neurophysiological improvement is caused by HAL training, and this result is different from the conventional brace treatment for knee collapse.

An interactive biofeedback could affect the patient's gait stability and memory. As the improvement in gait stability was sustained even 8-month follow-up after the intervention, a voluntary motion induced by robotic-assisted rehabilitation may have remained in the patient's memory.The present study had several methodological limitations. First, due to the spasticity, a walker was necessary during gait, which made it difficult to measure the ground reaction force. One previous study reported a positive effect of HAL training on kinetic data[7], but the ground reaction force needs to be considered. Second, the present study included only a single case report. Further research with more patients is necessary to confirm the present results.

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Conflict of interest

None.

REFERENCES

1) Tugui RD, Antonescu D: Cerebral palsy gait, clinical importance. Maedica (Buchar), 2013, 8: 388–393. [Medline]
2) Dobkin B, Apple D, Barbeau H, et al. Spinal Cord Injury Locomotor Trial Group: Weight-supported treadmill vs over-ground training for walking after acute incomplete SCI. Neurology, 2006, 66: 484–493. [Medline] [CrossRef]
3) Liston R, Mickelborough J, Harris B, et al.: Conventional physiotherapy and treadmill re-training for higher-level gait disorders in cerebrovascular disease. Age Ageing, 2000, 29: 311–318. [Medline] [CrossRef]
4) Kubota S, Nakata Y, Eguchi K, et al.: Feasibility of rehabilitation training with a newly developed wearable robot for patients with limited mobility. Arch Phys Med Rehabil, 2013, 94: 1080–1087. [Medline] [CrossRef]
5) Mizukami M, Yoshikawa K, Kawamoto H, et al.: Gait training of subacute stroke patients using a hybrid assistive limb: a pilot study. Disabil Rehabil Assist Technol, 2017, 12: 197–204. [Medline] [CrossRef]
6) Yoshikawa K, Mizukami M, Kawamoto H, et al.: Gait training with Hybrid Assistive Limb enhances the gait functions in subacute stroke patients: a pilot study. NeuroRehabilitation, 2017, 40: 87–97. [Medline] [CrossRef]
7) Fukaya T, Mutsuzaki H, Yoshikawa K, et al.: The training effect of early intervention with a Hybrid Assistive Limb after total knee arthroplasty. Case Rep Orthop, 2017, 2017: 6912706. [Medline]
8) Matsuda M, Mataki Y, Mutsuzaki H, et al.: Immediate effects of a single session of robot-assisted gait training using Hybrid Assistive Limb (HAL) for cerebral palsy. J Phys Ther Sci, 2018, 30: 207–212. [Medline] [CrossRef]
9) Palisano R, Rosenbaum P, Walter S, et al.: Development and reliability of a system to classify gross motor function in children with cerebral palsy. Dev Med Child Neurol, 1997, 39: 214–223. [Medline] [CrossRef]
10) Woltring HJ: A Fortran package for generalized, cross-validatory spline smoothing and differentiation. Adv Eng Softw, 1986, 8: 104–113. [CrossRef]
11) Patikas D, Wolf SI, Schuster W, et al.: Electromyographic patterns in children with cerebral palsy: do they change after surgery? Gait Posture, 2007, 26: 362–371. [Medline] [CrossRef]
12) Riad J, Modlesky CM, Gutierrez-Farewik EM, et al.: Are muscle volume differences related to concentric muscle work during walking in spastic hemiplegic cerebral palsy? Clin Orthop Relat Res, 2012, 470: 1278–1285. [Medline] [CrossRef]