

Longitudinal Gait Improvement With Multimodal Treatment and Repeated Hybrid Assistive Limb Gait Training in Hereditary Spastic Paraplegia: A Case Report

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Abstract

Hereditary spastic paraplegia (HSP) is a progressive neurodegenerative disorder characterized by lower-limb spasticity and gait impairment. Although spasticity management, including botulinum toxin injections, intrathecal baclofen therapy, and orthopedic surgery, can reduce spasticity and improve limb alignment, translating these improvements into meaningful gains in walking remains challenging. Robot-assisted gait training with wearable exoskeletons, such as the Hybrid Assistive Limb (HAL), may facilitate task-specific gait practice by assisting voluntary movements based on the user's motor intention. We report the case of a 64-year-old man with spastic paraplegia type 4 (SPG4), a subtype of HSP associated with pathogenic variants in the SPAST gene, who underwent stepwise spasticity management combined with repeated HAL-assisted gait training over long-term follow-up. Botulinum toxin injections were initiated at presentation, followed by intrathecal baclofen therapy during follow-up and tendon lengthening surgery. HAL-assisted gait training was performed repeatedly from Month 29 to Month 49. Over the course of treatment, walking speed and 2-minute walk distance gradually improved, whereas cadence remained relatively stable. These functional gains persisted despite a temporary decline. These sequential interventions may have provided a therapeutic foundation for subsequent gait reconstruction through repeated task-specific gait training using the HAL. Although the individual effects of each intervention cannot be determined from a single case, this clinical course suggests that integrating impairment-oriented interventions with repeated HAL-assisted gait training can optimize functional walking outcomes in patients with HSP.

Categories: Neurology, Physical Medicine & Rehabilitation

Keywords: botulinum toxin injection, case report, hereditary spastic paraplegia, hybrid assistive limb (hal), intrathecal baclofen therapy, neurorehabilitation, robot-assisted gait training, spasticity management, tendon lengthening surgery

Introduction

Hereditary spastic paraplegia (HSP) is a group of inherited neurodegenerative disorders characterized by progressive lower-limb spasticity and weakness due to degeneration of the corticospinal tract [1,2]. Among the genetic subtypes of HSP, spastic paraplegia type 4 (SPG4) is associated with pathogenic variants in the SPAST gene and is characterized by progressive lower-limb spasticity and gait impairment. These impairments predominantly affect the lower extremities and commonly lead to gait disturbances, which are among the most prominent disabling manifestations of the disease [3]. As the disease progresses, patients frequently experience reduced walking speed, impaired stability, and increasing difficulty with independent ambulation [4-6]. Gait analysis studies have demonstrated that individuals with HSP exhibit abnormal lower-limb coordination, altered muscle activation patterns, and reduced dynamic postural stability during walking, which may contribute to progressive gait dysfunction [7-9]. Therefore, preserving or improving gait function is an important goal in the clinical management of HSP.

Spasticity management in HSP may involve a combination of interventions, including botulinum toxin injections [10,11], intrathecal baclofen (ITB) therapy [12,13], orthotic management, and orthopedic surgery. These approaches may reduce spasticity, improve joint range of motion, and correct lower limb alignment. However, reductions in spasticity or correction of contractures do not necessarily result in meaningful improvements in gait performance, and additional rehabilitation strategies may be needed to translate improvements into functional gains [14]. Robot-assisted gait training using wearable exoskeletons has emerged as a rehabilitation approach for patients with neurological and neuromuscular disorders. The Hybrid Assistive Limb (HAL) is a wearable robotic exoskeleton that assists voluntary lower-limb movements based on bioelectrical signals generated by the user's intended movement [15-17]. In patients with HSP,

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robot-assisted gait training may support repetitive, task-specific gait practice following spasticity reduction or orthopedic correction. A previous multicenter randomized controlled trial demonstrated improvements in the 2-minute walk distance (2MWD) following a nine-session HAL-assisted gait training program in patients with neuromuscular diseases [16]. In patients with HSP, a recent case report described short-term functional gains after ITB administration combined with a single course of HAL-assisted gait training [18]. However, the long-term clinical course of repeated HAL-assisted gait training integrated with ongoing spasticity management, orthotic management, and orthopedic surgery has not been well characterized [19].

Therefore, we report the case of a patient with SPG4-related HSP who underwent stepwise spasticity management, tendon lengthening surgery, orthotic management, and repeated HAL-assisted gait training, with longitudinal changes in gait performance assessed during long-term clinical follow-up. The aim of this report is to describe longitudinal changes in gait performance during this multimodal treatment course, with particular attention to whether walking performance was maintained or improved across repeated HAL-assisted gait training courses.

Case Presentation

This case report was prepared in accordance with the CAsE REport (CARE) guidelines. In this report, time points are described relative to the initial presentation to our rehabilitation department, which was defined as Month 0. The patient was diagnosed with SPG4-related HSP caused by a pathogenic variant in the SPAST gene 12 years before presentation. His gait disturbance gradually progressed, and he began using a T-cane for ambulation five years before presentation. He was referred to our rehabilitation department in Month 0 for evaluation and management of progressive gait impairment. At the initial visit, he was 64 years old and had a Functional Ambulation Category (FAC) score [20] of 5 and a Barthel Index [21] of 90. He was able to ambulate with a T-cane. The patient's clinical characteristics and treatment course are summarized in Table 1.

Characteristic	Value
Age at initial visit (years)	64
Age at diagnosis (years)	52
Sex	Male
Genetic subtype	SPG4
Barthel Index at initial visit	90
FAC	5
Assistive device	T-cane
Botulinum toxin injections	Started in Month 0
ITB pump implantation	Month 16
ITB dose during follow-up	40-84 µg/day
Tendon lengthening surgery	Month 41
HAL training initiated	Month 29
HAL therapy	
Number of courses	7
Sessions per course	9
Total sessions	63

TABLE 1: Patient characteristics and clinical interventions.
SPG4, spastic paraplegia type 4; FAC, Functional Ambulation Category; ITB, intrathecal baclofen; HAL, Hybrid Assistive Limb

Clinical gait assessment revealed an equinovarus pattern, with absent heel contact at the initial visit. To manage lower-limb spasticity, botulinum toxin type A (onabotulinumtoxinA) injections were initiated in Month 0 and repeated during follow-up. The total dose ranged from 150 to 250 units per session, with the main target muscles being the gastrocnemius, soleus, and tibialis posterior muscles. These injections were

intended to reduce equinovarus-related spasticity and improve foot positioning during walking. However, gait impairment and lower limb spasticity gradually progressed. An ITB trial was performed in Month 11, followed by ITB pump implantation in Month 16. The initial ITB dose was 45 µg/day and was subsequently titrated according to clinical response, ranging from 40 to 84 µg/day during follow-up. After ITB pump implantation, a metal-supported short-leg brace was prescribed to improve ankle stability during gait, and gait training with the orthosis was initiated.

HAL-assisted gait training using the HAL (Cyberdyne Inc., Tsukuba, Japan) was initiated in Month 29. Each HAL-assisted gait training course was conducted during hospitalization and consisted of nine sessions of approximately one hour per day. Seven HAL-assisted gait training courses were conducted between Month 29 and Month 49. Treatment adherence and tolerability were monitored clinically by the treating therapists throughout each course based on patient-reported fatigue and pain, skin condition, fall risk, and the need for rest or discontinuation. The patient completed all seven HAL-assisted gait training courses, comprising 63 sessions in total. The timing and sequence of major interventions during follow-up are illustrated in Figure 1.

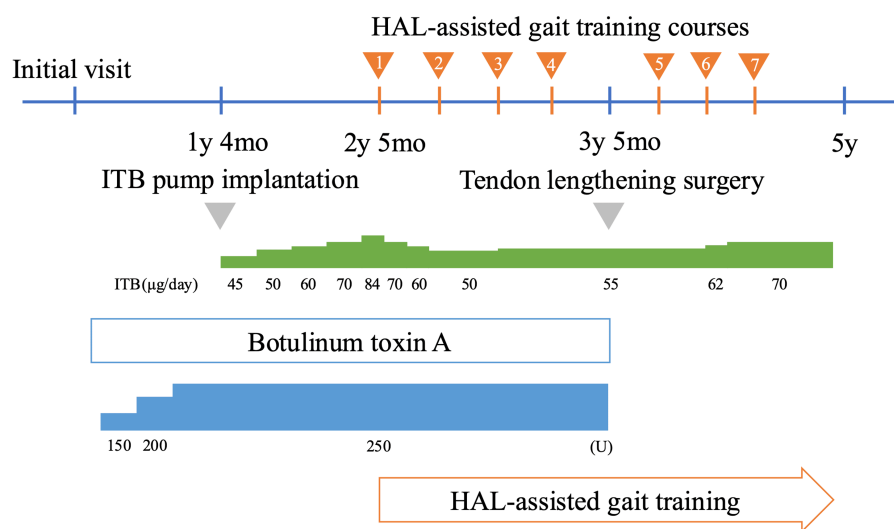


FIGURE 1: Timeline of major clinical interventions during follow-up.

Clinical timeline showing major interventions, including botulinum toxin injections, ITB therapy, tendon lengthening surgery, and HAL-assisted gait training courses. The timeline illustrates how repeated HAL-assisted gait training was integrated with ongoing spasticity management and surgical correction rather than being implemented as an isolated intervention.

The image was created using Microsoft PowerPoint (Microsoft Corporation, Redmond, WA).

ITB, intrathecal baclofen; HAL, Hybrid Assistive Limb; U, units; y, years; mo, months

Gait performance was assessed before and after each HAL-assisted gait training course. Walking speed was measured using the 10-m walk test performed at maximum walking speed, and cadence was recorded during the same test. Walking endurance was evaluated using the 2MWD. This measure was selected to align with a previous multicenter randomized controlled trial of HAL-assisted gait training in patients with neuromuscular diseases, in which the distance covered during the 2-minute walk test was used as the primary endpoint [16]. All gait assessments were performed without HAL or orthosis, with a safety hoist used for fall prevention. Assessment conditions were kept consistent between the pre- and post-course assessments within each HAL-assisted gait training course.

During the follow-up period, an additional surgical intervention was performed to address persistent lower-limb contractures and gait abnormalities. Despite repeated botulinum toxin injections and ITB therapy, limited ankle dorsiflexion persisted. Ankle dorsiflexion range of motion improved from -20° to -15° to -10° after botulinum toxin injections, but no further improvement was achieved. Static ankle plantar flexor spasticity was relatively mild, with a Modified Ashworth Scale score [22] of 1, suggesting that structural contracture rather than dynamic spasticity alone contributed to the persistent equinovarus posture (Table 2).

Table with 4 columns: Intervention, Baseline (R/L), After botulinum toxin injections (R/L), After tendon lengthening surgery (R/L). Rows include ROM Ankle dorsiflexion, MAS Hip adductors, and Ankle plantar flexors.

TABLE 2: Changes in spasticity and ankle range of motion before and after interventions.
MAS, Modified Ashworth Scale; ROM, range of motion; R/L, right/left

In Month 41, lower-limb tendon lengthening surgery involving the gastrocnemius, flexor digitorum longus, flexor hallucis longus, tibialis posterior, and adductor longus muscles was performed. After surgery, heel contact during gait was achieved, and botulinum toxin injections were no longer required. No adverse events, including falls, skin problems, severe pain, excessive fatigue requiring discontinuation, or ITB pump-related complications, occurred during the HAL-assisted gait training courses.

Walking speed increased from 0.66 m/s before the first course to 1.12 m/s after the seventh course. The 2MWD increased from 75.8 to 123.1 m over the same period, whereas cadence changed from 83.2 to 93.6 steps/minute. Although cadence showed moderate fluctuations, it remained relatively stable throughout the follow-up period. Longitudinal changes in gait performance across the HAL-assisted gait training courses are presented in Figure 2, and the detailed pre- and post-course values are presented in Table 3.

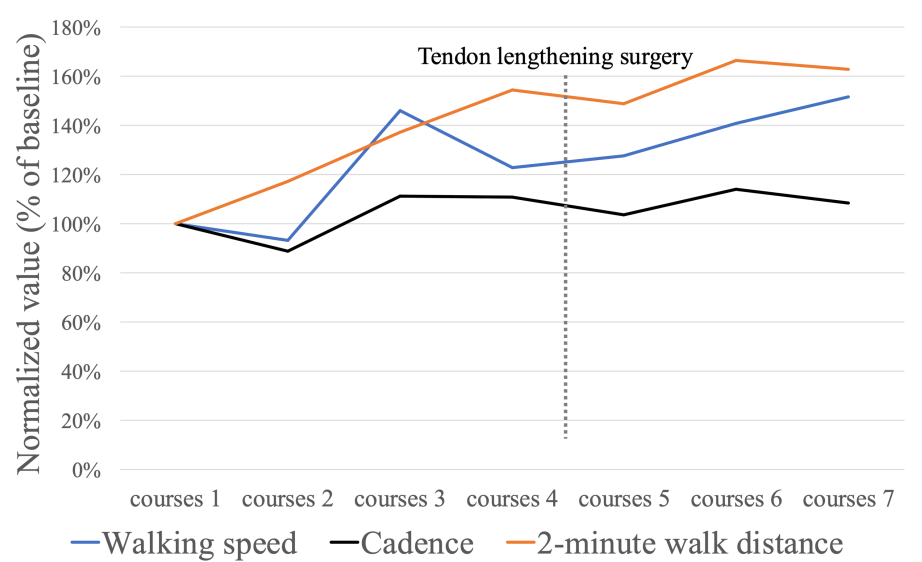


FIGURE 2: Longitudinal changes in gait performance across HAL-assisted gait training courses.
Longitudinal changes in pre-course walking speed, cadence, and 2-minute walk distance across seven HAL-assisted gait training courses. For each parameter, the pre-course value at each training course was divided by the corresponding pre-course value of the first course and multiplied by 100, with the first pre-course assessment defined as 100%. Only pre-course values are displayed. Gait assessments were performed without HAL or orthoses during overground walking using a safety hoist for fall prevention. Tendon lengthening surgery was performed between the fourth and fifth HAL-assisted gait training courses. Walking speed and 2-minute walk distance showed overall increasing trends during follow-up, whereas cadence exhibited smaller changes.
HAL, Hybrid Assistive Limb

Course and period			Walking speed (m/s)	Cadence (steps/minute)	2MWD (m)
1	Month 29	Pre	0.66	83.2	75.8
		Post	0.53	69.8	82
2	Month 33	Pre	0.62	74.0	89
		Post	0.77	87.9	99
3	Month 37	Pre	0.96	92.6	104
		Post	1.06	114.2	119
4	Month 40	Pre	0.81	92.4	117.2
		Post	0.80	90.6	110.1
5	Month 43	Pre	0.85	86.1	112.8
		Post	0.85	91.4	109.4
6	Month 45	Pre	0.93	94.9	126.3
		Post	1.04	93.2	126.4
7	Month 49	Pre	1.00	90.1	123.6
		Post	1.12	93.6	123.1

TABLE 3: Changes in gait parameters before and after each HAL-assisted gait training course.

Walking speed was calculated from the 10-m walk test performed at maximum walking speed. All gait assessments were performed without HAL or orthoses during overground walking using a safety hoist for fall prevention. The assessment conditions were kept consistent between pre- and post-course assessments within each HAL-assisted gait training course.

2MWD, 2-minute walk distance; HAL, Hybrid Assistive Limb

Although the magnitude and direction of immediate pre-post changes varied across courses, walking speed and 2MWD showed an overall increasing trend during long-term follow-up. Overall, the patient’s walking performance improved during a period of multimodal treatment that included pharmacological spasticity management, ITB therapy, tendon lengthening surgery, orthotic management, and repeated HAL-assisted gait training. During the follow-up period, the patient subjectively reported greater ease of walking. However, a formal structured patient perspective was not collected.

Discussion

In the present case, gait performance improved longitudinally during a multimodal treatment strategy that included botulinum toxin injections, ITB therapy, orthotic management, tendon lengthening surgery, and repeated HAL-assisted gait training. Walking speed and 2MWD showed an overall increasing trend during the follow-up period, despite temporary fluctuations around the time of tendon lengthening surgery. Although the independent contribution of each intervention could not be determined because the interventions were implemented sequentially and overlapped partially, the clinical course suggested that impairment-directed treatment and repeated task-specific gait training may be complementary components in supporting functional walking. A recent case report described short-term functional gains after intrathecal baclofen administration combined with one course of HAL-assisted gait training in a patient with HSP [18]. The present case extends this previous observation by describing longitudinal gait changes across seven repeated HAL-assisted gait training courses over approximately 20 months during a multimodal treatment pathway that included repeated botulinum toxin injections, ITB pump implantation, orthotic management, and tendon lengthening surgery. Thus, rather than focusing on the short-term effect of a single combined intervention, the present case provides additional information on how gait performance may evolve during long-term integration of impairment-oriented interventions and repeated task-specific gait training.

Spasticity management is an important component of the treatment of HSP, and previous studies have demonstrated that botulinum toxin injections and ITB therapy can reduce lower-limb spasticity [10-13]. However, reductions in spasticity alone do not necessarily lead to meaningful improvements in gait function [14,17]. From a clinical perspective, impairment-level changes, such as reduced spasticity, improved ankle range of motion, and improved lower-limb alignment, need to be translated into functional gait

performance. In the present case, botulinum toxin injections and ITB therapy were followed by orthotic management and task-specific gait training, which may have supported the transition from impairment management to functional walking practice [23]. This clinical sequence supports the view that spasticity reduction may be better considered as part of a broader rehabilitation strategy than as an endpoint of treatment.

Tendon lengthening surgery was another important component of the treatment strategy. Before surgery, ankle dorsiflexion remained limited despite repeated botulinum toxin injections and ITB therapy, suggesting that structural contracture contributed to the persistent equinovarus posture. After surgery, heel contact during gait was achieved, and botulinum toxin injections were no longer required. Improved foot alignment and initial contact may have contributed to greater gait stability; however, tendon lengthening can also reduce plantar flexor power and push-off efficiency. Therefore, the subsequent improvement in walking speed and 2MWD cannot be attributed to surgery alone and should be interpreted in the context of other pharmacological, surgical, orthotic, and rehabilitation interventions.

Repeated HAL-assisted gait training may have contributed to task-specific gait practice during periods of changing lower-limb tone, alignment, and orthotic use. The HAL assists voluntary movement based on bioelectrical signals associated with the user's intended movement, potentially facilitating repeated practice of gait cycles. In the present case, HAL-assisted gait training was introduced after stepwise spasticity management and continued before and after tendon lengthening surgery. Rather than acting as an isolated intervention, HAL-assisted gait training may function as a rehabilitation tool to consolidate the effects of spasticity reduction, orthopedic correction, and orthotic management on functional walking. Although this interpretation remains hypothetical because detailed biomechanical and electrophysiological analyses were not performed, the longitudinal course suggests that repeated task-specific gait training may be useful when muscle tone, limb alignment, and walking conditions change dynamically.

However, longitudinal patterns of gait performance require careful interpretation. Walking speed and 2MWD showed overall increasing trends, whereas cadence remained relatively stable. This pattern suggests that the increase in walking speed may not have been driven primarily by a higher stepping rate and could potentially reflect changes in step length, foot contact, or gait efficiency. The partial dissociation between walking speed and 2MWD across training courses should be interpreted cautiously because the maximum walking speed during the 10-m walk test reflects short-distance walking capacity, whereas the 2MWD reflects sustained walking ability and may be influenced by endurance, fatigue, balance, and pacing. Although stride length, joint kinematics, muscle activity, and kinetic data were not measured, the combined improvement in short-distance walking speed and endurance may indicate clinically meaningful gains across different aspects of gait performance. Similarly, although functional gains appear to persist across repeated training courses, the present case did not demonstrate a carryover effect or lasting changes in motor control.

This case also suggests that repeated HAL-assisted gait training is feasible in patients with HSP undergoing complex management of spasticity. Seven HAL-assisted gait training courses were completed during the follow-up period, and no adverse events, including falls, skin problems, severe pain, excessive fatigue requiring discontinuation, or ITB pump-related complications, occurred during the training courses. This observation is clinically relevant because long-term rehabilitation strategies for slowly progressive neurological disorders must not only be potentially effective but also feasible and safe.

This study has several limitations. First, this was a single case report, and the findings cannot be generalized to other patients with HSP. Second, because botulinum toxin injections, ITB therapy, orthotic management, tendon lengthening surgery, and HAL-assisted gait training were implemented sequentially and partially overlapped, the individual effects of each intervention could not be isolated. Third, detailed biomechanical and electrophysiological assessments, including three-dimensional gait analysis, surface electromyography, and kinetic analysis, were not performed. Consequently, changes in gait patterns, motor learning, and motor control mechanisms remain unclear. Fourth, serial quantitative assessments of muscle strength were not available, preventing evaluation of the contribution of changes in muscle strength to gait performance. Finally, gait assessments were performed without HAL or orthoses but with a safety hoist for fall prevention. As gait performance in patients with HSP may be influenced by assessment conditions, including the use of safety support, the results should be interpreted in the context of these standardized assessment conditions. Further studies involving larger cohorts, standardized gait assessment conditions, and comprehensive biomechanical assessment are needed to clarify the role of integrated treatment strategies in HSP.

Conclusions

This case illustrates longitudinal improvement in gait performance during multimodal management involving botulinum toxin injections, ITB therapy, tendon lengthening surgery, orthotic management, and repeated HAL-assisted gait training in a patient with SPG4-related HSP. Spasticity reduction and orthopedic correction should not be considered final therapeutic goals in isolation but may provide a foundation for subsequent gait reconstruction through repeated task-specific gait training. This case highlights the potential importance of combining impairment-oriented interventions with repeated HAL-assisted gait training to optimize functional walking outcomes in patients with HSP.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Acquisition, analysis, or interpretation of data: Taiyo Kawaguchi, Takatoshi Hara, Yuta Miyazaki, Ayano Matsui, Yuki Hara, Keiko Sone, Takeshi Matsuura, Yuji Takahashi

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Critical review of the manuscript for important intellectual content: Taiyo Kawaguchi, Takatoshi Hara, Yuta Miyazaki, Ayano Matsui, Yuki Hara, Keiko Sone, Takeshi Matsuura, Yuji Takahashi, Tetsuya Tsuji, Masahiro Abo

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. The Ethics Review Committee of the National Center of Neurology and Psychiatry issued approval A2024-122. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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