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Case Study

Effects of robot exoskeletal-assisted gait training on gait ability in a pediatric patient with peripheral polyneuropathy: a case report

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Abstract. [Purpose] This study aims to investigate the effects of robotic exoskeleton-assisted gait training on a pediatric patient with peripheral polyneuropathy. [Participant and Methods] A 10-year-old boy with lower extremity weakness attributed to peripheral polyneuropathy underwent a two-week program comprising 10 rehabilitation sessions of powered robotic exoskeleton-assisted gait training (REGT). He was evaluated before and after treatment using the 10-meter walk test, 6-minute walk test, Berg Balance Scale, the Timed Up and Go Test, the Functional Reach Test, the Modified Functional Reach Test, hip and knee flexion/extension angles, and cardiopulmonary exercise testing. [Results] The patient demonstrated improved gait speed, balance, joint mobility, cadence, the maximum oxygen consumption and metabolic equivalents after the REGT. [Conclusion] Robotic exoskeleton devices could provide additional benefits to pediatric patients with peripheral polyneuropathy, pending larger studies to confirm the significance of treatment.
Key words: Exoskeletal robotic gait training, Pediatric, Peripheral polyneuropathy

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INTRODUCTION

Gait disturbances in pediatric patients resulting from peripheral polyneuropathy, such as Guillain–Barré syndrome (GBS), are well-documented, although there are also numerous cases where the cause is unknown. The prognosis is generally favorable[1–3]; however, instances of poor prognosis and residual sequelae leading to functional limitations have been reported[4, 5].

Robot-assisted gait training is widely used in physical therapy as an effective method for improving gait. In the established tethered robot gait training approach, a ceiling-mounted harness and a treadmill-based exoskeleton are employed, providing facilitated walking via a predetermined gait pattern. This method effectively supports standing and walking activities but necessitates passive assistance from a minimum of two therapists. The untethered exoskeleton robot represents a novel and improved version aimed at overcoming the limitations of tethered robots. It consists of a wearable articulated suit with a self-contained power source and a control algorithm, reducing the need for multiple therapists while significantly alleviating the patient's physical constraints, enabling them to move more freely[6, 7]. It has primarily been used in patients with central nervous system (CNS) rather than peripheral nervous system (PNS) diseases.

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Existing research investigating the use of Angel Legs robots[8)] (ANGELROBOTICS Co., Ltd., Seoul, Korea) includes two adult patients with peripheral nerve injuries and two adult patients with chronic inflammatory demyelinating polyneuropathy (CIDP). No research has been conducted on acute pediatric PNS patients. This case report details the therapeutic effects of the Angel Legs robot on a pediatric patient with peripheral polyneuropathy

PARTICIPANT AND METHODS

A 10-year-old boy presented to the Jeonbuk National University Hospital pediatric department with a two-day history of gait disturbance, dizziness, and headache. The participant weighed 39.5 kg and had a height of 145.2 cm. After admission, he also developed weakness in both lower extremities. He underwent brain and spine magnetic resonance imaging, a nerve conduction study, electromyography, and an otorhinolaryngological examination, which did not reveal any specific findings. Although GBS was not indicated in the initial cerebrospinal fluid study, the patient's test results were positive for GM1 antibodies (IgM). Therefore, he was treated for possible GBS or another peripheral polyneuropathy.

Following five intravenous immunoglobulin treatments, the patient's muscle strength improved. Three weeks after presenting with his initial symptoms, the patient was transferred to the Department of Rehabilitation Medicine for further rehabilitation of his lower extremities and to treat his gait disturbance.

At the time of transfer, the patient's bilateral lower extremities manual muscle test performance was good (Medical Research Council (MRC) grade 4). He was unable to walk independently and scored 16 points on the Berg Balance Scale (BBS). This study was approved by the Institutional Review Board (IRB) of Jeonbuk National University Hospital (IRB number 2024-01-005) and qualifies for exemption from deliberation and consent requirements.

Due to the patient's gait disturbance, conventional physical and occupational therapies were started first. After 20 days of conventional rehabilitation therapy, the patient's motor function had improved, enabling him to walk with supervision. Subsequently, we proceeded with robotic exoskeleton-assisted gait training (REGT).

The patient and his parents consented to REGT and actively participated with a positive attitude. The two-week program consisted of ten sessions, each with a duration of 30 minutes. The first and final five minutes of each session were dedicated to equipment setup and removal, leaving 20 minutes for gait training. The gait training was performed using the walking mode of the Angel Legs exoskeleton robot. All the training sessions and functional assessments were conducted at Jeonbuk National University Hospital Pediatric Rehabilitation Center by specialized physical therapists.

The REGT used the (child-sized) Angel Legs M20-A (ANGELROBOTICS Co., Ltd., Seoul, Korea, dimensions: 390–510 mm [W] × 370–435 mm [D] × 1,170–1,430 mm [H]; weight, 14.2 kg), an untethered wearable torque-assisting exoskeleton robot. The robot automatically recognizes the wearer's gait phase through ground contact sensors, encoders, and actuators. Accordingly, it provides joint torque assistance to the hips and knees. The robot is equipped with a dedicated tablet attached to a backpack, enabling customization of its assisting force. Squatting, walking, or stair-climbing mode can be selected depending on the training objectives. Hip and knee flexion/extension angles, a spatiotemporal index, and information about the gait phases can be obtained and assessed by utilizing the gait analysis report program.

Functional assessments were performed before and after the 10 REGT sessions (pre-test, post-test) without the use of any other gait-assistive devices. Gait speed was evaluated using the 10-meter walk test (10MWT) and the 6-minute walk test (6MWT). Balance tests included the BBS, the Functional Reach Test (FRT), the Modified Functional Reach Test (mFRT), and the Timed Up and Go (TUG) test. FRT/mFRT consists of two practice trials and three test trials, with the distances of the last three trials averaged to determine the patient's score. Measurements of hip and knee flexion/extension angles as well as cadence were taken by Angel Legs' built-in gait analysis program. Lastly, exercise capacity was assessed by ascertaining the maximum oxygen consumption (VO_2 max) and metabolic equivalents (METs) during cardiopulmonary exercise testing (CPET). CPET was conducted on an ergometer following a predetermined protocol, increasing intensity every minute until the patient could no longer continue, with the aim of reaching the patient's maximum capacity.

RESULTS

After the 2-week robotic gait training program, the patient showed improved gait speed (Table 1), balance (Table 2), hip and knee flexion/extension angles (Fig. 1), and cardiopulmonary function (Table 3).

Table 1. Gait speed

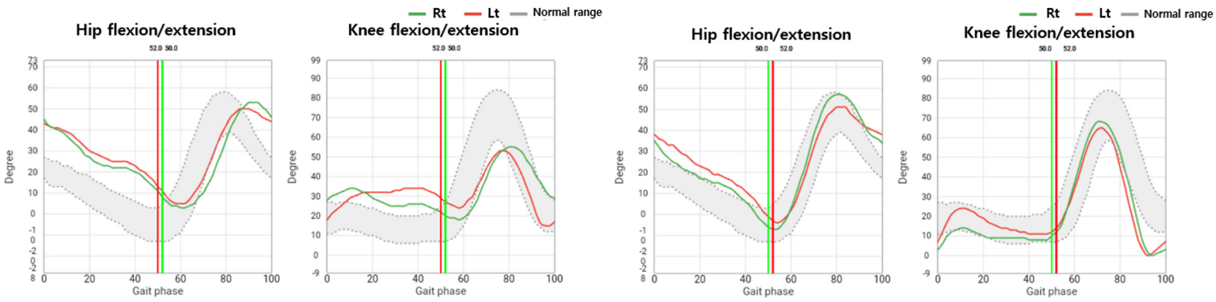
	Pre-treatment	Post-treatment
10MWT (Comfortable speed, m/s)	0.65	1.24
10MWT (Maximum speed, m/s)	0.81	1.91
6MWT (Total distance, m)	333	526
6MWT (Average speed, m/s)	1.11	1.75

10MWT: 10-meter walk test; 6MWT: 6-minute walk test; m: meter; m/s: meter/second.

Table 2. Balance test

	Pre-treatment	Post-treatment
BBS	37	50
TUG	10.5	7.8
FRT/mFRT		
Anterior reach (sitting, cm)	32	49.5
Anterior reach (standing, cm)	22	42
Lateral reach (sitting, rt, cm)	25.5	44
Lateral reach (sitting, lt, cm)	20	42.5
Lateral reach (standing, rt, cm)	21	42
Lateral reach (standing, lt, cm)	19.5	41

BBS: Berg balance scale; TUG: timed up and go; FRT: functional reach test; mFRT: modified functional reach test; cm: centimeters; lt: left; rt: right.



Pre-test
Cadence (left, right): 68.6, 69.6

Post-test
Cadence (left, right): 79.8, 78.1

Fig. 1. Hip and knee flexion/extension angles.
The gray section indicates the normal range of hip and knee flexion/extension angles during gait in healthy individuals. The patient's hip and knee flexion and extension angles were outside the normal range in the pre-treatment test but aligned more closely with the normal range post-treatment. Rt: right; Lt: left.

Table 3. Cardiopulmonary exercise testing

	Pre-treatment	Post-treatment
VO_2 max (L/min)	0.65	1.24
METs (ml/kg/min)	0.81	1.91
Maximal exercise time (sec)	333	526

METs: metabolic equivalents; VO_2 max: maximum rate of oxygen consumption.

In the 10MWT, the comfortable walking speed improved from 0.65 m/s at baseline to 1.24 m/s post-training. The maximum walking speed increased from 0.81 m/s to 1.91 m/s after training. In the 6MWT, the total walking distance improved from 333 m to 526 m. The average walking speed also increased from 1.11 m/s to 1.75 m/s. The BBS score improved from 37 points to 50 points. The TUG test time reduced from 10.5 seconds to 7.8 s. The results of FRT/mFRT also showed improvement in anterior, lateral, and standing reaches in centimeters after training. The patient's hip and knee flexion/extension angles during gait became closer to normal ranges after training. The cadence improved from 68.6/69.6 steps per minute to 79.8/78.1 steps per minute.

After the REGT intervention, the patient's gait disturbance improved remarkably, enabling him to walk independently and perform complex movements such as climbing stairs.

DISCUSSION

A pediatric patient with acute peripheral polyneuropathy underwent REGT, after which his gait speed, balance, gait parameters, and cardiopulmonary function improved. Moreover, the patient demonstrated clinical enhancements in daily activities, such as walking and climbing stairs, following the intervention. This may indicate improvement in the patient's walking abilities following the treatment. REGT facilitates intentional active walking, allowing patients to move freely and enhancing treatment compliance. This can promote the reactivation of damaged neural pathways and strengthen muscle power. This neuroplastic effect, along with the repetitive practice of proper gait patterns and the targeted muscle strengthening provided by REGT, likely underlies the observed improvements in the patient's overall gait performance[8)].

In a previous study investigating the effects of REGT on adults with CIDP and peripheral nerve injuries, evaluations were conducted using the adjusted MRC scale, BBS, functional ambulation category, trunk control test, cadence, and joint torque[9)]. We conducted a more comprehensive assessment using the 10MWT, 6MWT, BBS, FRT/mFRT, TUG, cadence, joint angle data, and CPET.

This is the first reported case of a pediatric peripheral polyneuropathy patient undergoing REGT, distinguishing it from previous studies that primarily investigated REGT for pediatric patients with cerebral palsy[6, 7, 10)]. Our results indicate that REGT may have a broad applicability not only for patients with CNS but also those with peripheral neuropathy. The scope of robot-assisted therapy could be widened to encompass additional patient populations with gait impairments, including those with intellectual disabilities and arthritis.

Previous studies investigating the prognosis for pediatric GBS patients have reported that the mean duration to independent walking is 2.97 ± 3.02 months, and over 80% of these patients can walk again within months[2, 11)]. We expected REGT to reduce the functional recovery time to independent gait. Our patient achieved independent gait 2 months after the onset of their symptoms, shorter than the mean time of three months.

Other potential factors contributing to the improvement in the patient's gait disturbance should be considered as should whether, their functional recovery can be attributed to the natural resolution of the disease or the therapeutic effects of the robot. Further investigation is necessary to confirm the effectiveness of REGT in PNS disease patients—specifically, a large study involving a greater number of patients is needed for more conclusive results. In our study, the patient demonstrated greater improvements in lateral reach compared to anterior reach during the FRT assessment. This finding suggests that REGT may have contributed more to enhancing the patient's bilateral balance abilities than their anteroposterior balance. However, as these results are based on a single patient, further studies involving a larger number of patients are necessary to confirm these findings.

At 14.2 kg, the robot may impose a considerable load, particularly on patients experiencing weakness in the lower extremities. In our case study, the patient experienced discomfort due to the weight of the device. The patient's tolerance for the device's weight must be considered before embarking on REGT. Additionally, a therapist should accompany the patient to prevent falls and ensure their safety during training.

Initially, our patient's goal was stair climbing, so the Angel Legs' stair-climbing mode was used. However, unlike the walking mode, which provided gait assistance when the patient exerted a certain level of force, the stair-climbing mode gave assistance in response to minimal effort from the patient, resulting in less intensive exercise. Therefore, the walking mode appeared to be more effective.

In previous studies, gait-related VO_2 max and METs were assessed using a portable gas analyzer during REGT, but CPET was not conducted[6, 12, 13)]. We conducted CPET before and after treatment, which confirmed the improvements in VO_2 max and METs, and allowed a more accurate assessment of cardiorespiratory fitness by reaching the patient's maximum capacity.

A pediatric peripheral polyneuropathy patient underwent two weeks of rehabilitation comprising 10 REGT sessions. After the treatment, the patient's gait speed, balance, gait parameters, and cardiopulmonary function had all improved. However, to determine the significance of these effects, a larger study involving more patients is needed for further validation.

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Conflict of interest

All authors declare that there is no conflict of interest.

REFERENCES

1) Vanasse M, Rossignol E, Hadad E: Chronic inflammatory demyelinating polyneuropathy. Handb Clin Neurol, 2013, 112: 1163–1169. [Medline] [CrossRef]
2) Barzegar M, Toopchizadeh V, Maher MH, et al.: Predictive factors for achieving independent walking in children with Guillain-Barre syndrome. Pediatr Res, 2017, 82: 333–339. [Medline] [CrossRef]
3) Lupuşor SH: Acute inflammatory demyelinating polyneuropathy in children. J Rom Child Adolesc Neurol Psychiatry, 2014, 17: 3.
4) Prada V, Massa F, Salerno A, et al.: Importance of intensive and prolonged rehabilitative treatment on the Guillain-Barrè syndrome long-term outcome: a retrospective study. Neurol Sci, 2020, 41: 321–327. [Medline] [CrossRef]
5) Vajsar J, Fehlings D, Stephens D: Long-term outcome in children with Guillain-Barré syndrome. J Pediatr, 2003, 142: 305–309. [Medline] [CrossRef]
6) Hong J, Lee J, Choi T, et al.: Feasibility of overground gait training using a joint-torque-assisting wearable exoskeletal robot in children with static brain injury. Sensors (Basel), 2022, 22: 3870. [Medline] [CrossRef]
7) Yoo M, Ahn JH, Park ES: The effects of over-ground robot-assisted gait training for children with ataxic cerebral palsy: a case report. Sensors (Basel), 2021, 21: 7875. [Medline] [CrossRef]
8) Tortora S, Tonin L, Sieghartsleitner S, et al.: Effect of lower limb exoskeleton on the modulation of neural activity and gait classification. IEEE Trans Neural Syst Rehabil Eng, 2023, 31: 2988–3003. [Medline] [CrossRef]
9) Park GM, Cho SH, Hong JT, et al.: Effects and safety of wearable exoskeleton for robot-assisted gait training: a retrospective preliminary study. J Pers Med, 2023, 13: 676. [Medline] [CrossRef]
10) Beretta E, Storm FA, Strazzer S, et al.: Effect of robot-assisted gait training in a large population of children with motor impairment due to cerebral palsy or acquired brain injury. Arch Phys Med Rehabil, 2020, 101: 106–112. [Medline] [CrossRef]
11) Korinthenberg R, Mönting JS: Natural history and treatment effects in Guillain-Barré syndrome: a multicentre study. Arch Dis Child, 1996, 74: 281–287. [Medline] [CrossRef]
12) Jang YC, Park HK, Han JY, et al.: Cardiopulmonary function after robotic exoskeleton-assisted over-ground walking training of a patient with an incomplete spinal cord injury: case report. Medicine (Baltimore), 2019, 98: e18286. [Medline] [CrossRef]
13) Kim SH, Han JY, Song MK, et al.: Effectiveness of robotic exoskeleton-assisted gait training in spinocerebellar ataxia: a case report. Sensors (Basel), 2021, 21: 4874. [Medline] [CrossRef]