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Robotic Exoskeleton for Young Adult Large-Lesion Stroke: A Case Report

[1]Farida Arisanti*, [2]Alfi Yunita Sari, [3]Maria Agustina Sulistyo Wulandari, [4]Rinesa Larasati, [5]Vitriana

[1] Physical Medicine and Rehabilitation Department, Faculty of Medicine, Universitas Padjadjaran/Dr. Hasan Sadikin General Hospital, Bandung, West Java, Indonesia*; email: farida.arisanti@unpad.ac.id

[2] Slamet 39, Neurorehabilitation Center, Bandung, Indonesia; email: alfiyunita17@gmail.com

[3] Physical Medicine and Rehabilitation Department, Faculty of Medicine, Universitas Padjadjaran/Dr. Hasan Sadikin General Hospital, Bandung, West Java, Indonesia; email: magustinasw@gmail.com

[4] Physical Medicine and Rehabilitation Department, Faculty of Medicine, Universitas Padjadjaran/Dr. Hasan Sadikin General Hospital, Bandung, West Java, Indonesia; email: larasatirinesa@gmail.com

[5] Physical Medicine and Rehabilitation Department, Faculty of Medicine, Universitas Padjadjaran/Dr. Hasan Sadikin General Hospital, Bandung, West Java, Indonesia; email: vitriana@unpad.ac.id

*Correspondence

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Abstract

Introduction: *Large-lesion stroke in young adults often causes severe functional impairment, severely inhibiting people's reintegration and long-term autonomy. In the subacute phase, severe motoric weakness, postural instability, and decreased aerobic capacity often inhibit effective walking rehabilitation.* ***Objective:*** *To evaluate the potential benefits of integrating a robotic dermoskeleton (KEEOGO) into the "Assist-as-Needed" (AAN) framework to achieve overground walking and cognitive motor integration.* ***Method:*** *A 34-year-old male with subacute ischemic stroke who presented with right hemiparesis (Brunnstrom Stage 2) and severe ambulation disturbance. The patient participated in a 4 week program consisting of robotic-assisted overground walking sessions. The AAN methodology provides adaptive support, responding with motoric effort directly to the patient.* ***Results and Discussion:*** *Post-intervention outcomes showed significant improvement. Walking endurance, as measured by the 6-Minute Walk Test, shows a marked improvement, rising from 96 m to 145 m, gait speed (10-Meter Walk Test) improved from 0.25 m/s to 0.46 m/s and cognitive function (MoCA-Ina) improved from 11 to 20.* ***Conclusion:*** *Robotic-assisted overground walking using an adaptive exoskeleton may be a safe and effective adjunctive modality for improving motor and cognitive outcomes in young patients with large-lesion stroke.*

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Introduction

The incidence of stroke in young adults (commonly aged 18 – 49 years old) is increasingly reported and has consequences of long-term psychosocial and socioeconomic issues due to loss of productive years (Rasing *et al*., 2026; Cao et al., 2024). Improving independent walking ability is an important part of post-stroke rehabilitation and is closely related to people's participation in and ability to return to work (Crow & Smith, 2023). However, in the subacute phase, severe motoric disturbances, decreased endurance, asymmetrical weight-bearing, and cognitive deficits that accompany them may limit travel recovery (Cao *et al*., 2025).

Large-lesion stroke generally refers to extensive cerebral infarction associated with substantial neurological deficits and poor functional recovery. Previous studies have described large cerebral infarction as lesions involving more than one-third of the middle cerebral artery territory or infarct volumes exceeding 70–100 mL on diffusion-weighted imaging. Clinically, large infarctions are often associated with cortical dysfunction, severe motor impairment, and neuroimaging findings showing cortical or subcortical infarction greater than 1.5 cm in diameter (Kufner *et al*., 2020; Rojsanga *et al*., 2019).

Robotic technologies have developed to increase the number of repetitions, increase safety, and encourage early walking exercise. A recent study shows that overground walking with a robotic exoskeleton can improve walking outcomes, especially walking speed and other walking measures, despite limitations in the variation effect and the certainty of the evidence (Yang et al., 2024; Huo et al., 2024). The KEEOGO is a wearable robotic exoskeleton designed to assist with lower-limb movement during walking using an assist-as-needed concept. Clinical reports and reviews have described its feasibility and potential functional benefits for people with neurological conditions, including those who have had a subacute stroke (Rakhmatillaev & Bucinskas, 2024; Mcleod *et al*., 2019).

This case report describes the use of a KEEOGO robotic exoskeleton for task-oriented overground walking as part of a multidisciplinary rehabilitation programme for a young adult with a sub-acute large ischemic stroke, with a focus on functional outcomes relevant to community mobility.

Case Report

Case Presentation

This study was conducted as a single-patient case report describing the clinical application and functional outcomes of robotic exoskeleton–assisted overground walking in a young adult with a large lesion in subacute stroke. The report was prepared in accordance with the CARE guidelines for case reports.

Patient Information

The patient, a 34-year-old male, was diagnosed with a subacute ischaemic stroke affecting the left frontotemporal cortico-subcortical region and internal capsule, with large vasogenic oedema present (figure 1. Right-sided hemiparesis with Brunnstrom stage 2 and moderate cognitive impairment is the result). Prior to the stroke, he was independent in activities of daily living and ambulation. At the time of admission to the rehabilitation unit, he had impaired walking ability, reduced endurance and asymmetrical weight-bearing when standing and walking.

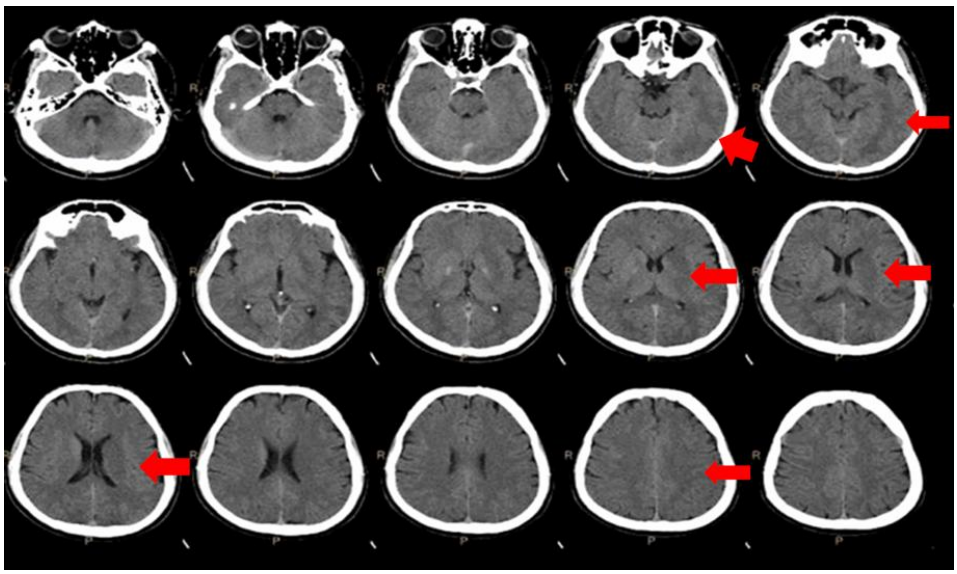

Figure 1. Neuroimaging via non-contrast head CT showed a broad hypodense area in the left middle cerebral artery territory (red arrow)

Intervention Protocol

A comprehensive outpatient rehabilitation program consisting of conventional physiotherapy and occupational therapy was participated in by the patient. Robotic exoskeleton-assisted overground walking using KEEOGO was also incorporated to improve walking ability.

The robotic intervention was administered weekly over a four-week period. Each training session included overground walking practice, using an assist-as-needed approach and allowed the device to provide support that adjusted based on the patient's voluntary effort and walking ability. The training focus on task-oriented walking, specifically targeting sit-to-stand transitions, maintaining the upright position, symmetrical weight distribution during stance, and step initiation and control throughout the swing phase. Furthermore, the progressive walking task was increased to include turning maneuvers, obstacle negotiation involving small curbs and cones, and stepping up and down a stepper. Throughout each session, safety supervision was provided.

A B C D

Figure 2. Walking training with Robotic Exoskeleton
A) Sit to stand B) Weight shifting in standing C) Weight acceptance at paretic side in stanc D) Obstacle negotiation

The robotic intervention was structured into 60-minute sessions. Each session consisted of a 7-minute setup and calibration period, followed by 30 minutes of net overground walking time (active ambulation). During this active phase, the patient completed about 600 to 800 steps in each session, focusing on task-specific movements like 180-degree turns and overcoming obstacles. The assistance level was set to the 'Assist-as-Needed' (AAN) mode, where the AI-driven torque assistance was dynamically adjusted to ensure the patient contributed maximum voluntary effort for knee extension during the stance phase and hip-knee coordination during the swing phase.

Table 1
Structure of the Robotic Exoskeleton Intervention Session

Session Phase	Duration	Primary Activities
Preparation &Calibration	7 Minutes	Device donning, synchronization of AI sensors with patient's gait pattern.
Active Ambulation	30 Minutes	Overground walking practice with a focus on task orientation.
Repetitions &Maneuvers	Variable	Completion of 600 to 800 steps per session, including 180-degree turns.
Obstacle Negotiation	Variable	Stepping over small curbs, cones, and up/down on a stepper.

Ethical Considerations

Written informed consent was obtained from the patient for participation in the rehabilitation program and for publication of this case report. Patient confidentiality was maintained throughout the study.

Functional Outcomes

Following four weeks of rehabilitation incorporating robotic exoskeleton–assisted overground walking, improvements were demonstrated by the patient across multiple functional domains compared with the baseline (Six-Minute Walk Test/6MWT, Ten-Meters Walk Test/ 10MWT, Weight Bearing Symmetry at paretic side using stabilometry and MoCA-INA scores) as shown in table 2.

Table 2
Analysis of Pre- and Post-Intervention Clinical Outcomes

Outcome Measure	Pre-intervention	Post-intervention	Change (%) / Unit
6MWT Distance	96 m	145 m	+51.04% (59 m)
10WMT Speed	0.25 m/sec	0.46 m/sec	+84% (0.21 m/sec)
Weight-bearing Symmetry	31.2%	48.4%	+17.2% (Paretic side)
MoCA-Ina Score	11	20	+9 points (Cognition)
Ambulation Status (FAC)	3 (Cane-assisted)	4 (Independent short dist.)	Improvement in independence

Abbreviations: 6MWT = Six-Minute Walk Test; 10MWT = Ten-Meter Walk Test; MoCA-Ina = Montreal Cognitive Assessment Indonesian Version; FAC = Functional Ambulation Category

Table 3
Clinical Event and Intervention Phase

	Clinical Event / Intervention Phase
Day 0	Acute ischemic stroke onset (Left Frontotemporal Region).
Week 2	Initial Rehabilitation Referral; presented with Brunnstrom Stage 2.
Week 3	**Baseline Assessment (T0):** MoCA-Ina, 6MWT, 10WMT, Weight bearing asymmetry.
Week 4 - 7	**Active Intervention Phase:** Weekly KEEOGO-assisted overground walking (4 sessions) + daily conventional PT/OT.
Week 8	**Final Assessment (T1):** Repeated outcome measures.
Follow-up	Transition to limited community ambulation (FAC 4).

1. Discussion

The recovery of walking ability is a central goal in post-stroke rehabilitation, particularly in young adults who face prolonged functional limitations during their productive years. In this case, significant improvements were demonstrated by the patient in walking endurance, postural symmetry, cognitive performance, walking speed and functional independence following a rehabilitation programme incorporating robotic exoskeleton–assisted overground walking using KEEOGO. These findings are consistent with the current body of evidence suggesting that task-oriented gait training supported by robotic technologies can promote functional recovery by facilitating repetitive, goal-directed walking practice in individuals with substantial motor impairment following a stroke regardless of whether they are in the subacute phase of recovery or in the chronic phase, eventhough individual responses can vary (Zou *et al*., 2024; Tiwari *et al*., 2025; Leow *et al*., 2023).

This case demonstrates improvement in walking endurance and asymmetric weight-bearing after a brief, structured presentation of walking with an exoskeleton helper combined with standard therapy. Improvement in cortical activation is associated with robotic exoskeleton training, particularly in the ipsilesional motor area and the bilateral prefrontal cortex. This tends to be important for neuroplasticity and motoric recovery in stroke patients. Overground walking exercise with robotic helper allows for a more coordinated walking pattern, is efficient, and encourages bilateral motoric network reorganization related to balance and walking recovery after stroke (Huo *et al*., 2024; Leow *et al*., 2023).

An important feature of the intervention in this case is the use of assist-as-needed (AAN) while doing overground walking. This method allows the robotic system to provide help only when needed, which encourages active participation and motor learning, not only passive movement (Leow *et al*., 2023; Zhang *et al*., 2025). This study shows that the assist-as-needed strategy, which was task-oriented, triggers greater muscle activity on the paretic side, especially at the knee joint and the plantar flexors, relative to the maximum assistance mode. Increasing activation is very important for encouraging neuroplasticity and improving gait pattern and walking performance post-stroke (Huo *et al*., 2024). Therefore, the improvement in postural symmetry and independent walking observed in this case may indicate better motor control, which is encouraged by this training method.

Exoskeleton rehabilitation robotics for the lower extremity, unilateral, offers overground gait training, combining weight bearing, walking, and balance, allowing patients to perform upright walking training with a combination of proprioceptive feedback and motor control training in the early stages of stroke (Huo *et al*., 2024; Mcleod *et al*., 2019).

In addition to improvements in motor function, cognitive screening also improved after the intervention period. Even though the causal-effect relationship cannot be concluded from a single case, recent evidence shows that walking exercise, which involves higher cognitive demands, such as walking overground with an adaptive helper, can positively influence cognitive-motor integration after stroke. Cognitive impairment is increasingly being recognised as a contributor to limited walking adaptability and reduced community ambulation, particularly in young stroke survivors (Tiwari *et al*., 2025; Leow *et al*., 2023; Zhang et al., 2025). The improvement in walking and cognitive measures that has been seen in this case may therefore reflect the interactive nature of motor and cognitive recovery during task-oriented rehabilitation and obstacle negotiation with exoskeleton-assisted walking training (Cao *et al*., 2025; Yang *et al*., 2024; Huo *et al*., 2024). The remarkable 9-point improvement in MoCA-Ina scores likely reflects a synergistic effect between the physiological resolution of vasogenic edema, which restores baseline cerebral perfusion and resolves diaschisis and the high cognitive demand of overground robotic training (GBD 2019 Stroke Collaborators, 2021; Winstein *et al*., 2016). Unlike passive therapies, the KEEOGO system requires active motor planning and involvement of the prefrontal cortex. This could potentially use the "primed" neural environment created by the reduction of swelling to speed up the integration of cognitive and motor functions (Mcleod *et al*., 2019; Gu *et al*., 2022).

From a clinical perspective, this case study suggests that using robotic exoskeletons to help people walk over ground could be a useful addition to rehabilitation programs for selected patients with subacute stroke. For young adults, improvements in walking speed, endurance, and walking performance are associated

with reintegration into the community and work (Rasing *et al*., 2026). Stroke rehabilitation guidelines nowadays emphasize the importance of intensive exercise and task-specificity for optimizing functional recovery (Winstein *et al*., 2016; Mehrholz *et al*., 2025; Hidler *et al*., 2009). The use of assistive technology, such as a robotic exoskeleton, can be a solution when conventional therapy is insufficient (Mehrholz *et al*., 2025; Hidler *et al*., 2009).

Several limitations should be acknowledged. Given its nature as a single case report, generalizability of the results is inherently limited, and the observed improvement may be partly attributed to spontaneous recovery during the subacute phase. Furthermore, the intervention is given once a week for 4 weeks, and the optimal dose and timing of exercise with the exoskeleton helper have not yet been determined. Consequently, further studies involving larger participant groups or a comparative methodology are very important to complete patient selection criteria, exercise protocols, and long-term functional benefits related to the implementation of robotic exoskeletons overground in stroke rehabilitation.

Conclusion

Robotic exoskeleton-assisted overground walking using an assist-as-needed approach may improve gait performance, postural symmetry, ambulation independence, and cognitive function in young patients with subacute large-lesion stroke.

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