Polish Annals of Medicine
Journal homepage: https://www.paom.pl

Review Paper

Effects of using lower limb exoskeleton on function and psychosocial well-being of stroke survivors: A review

Deepashini Harithasan[1], Aiman Mat Najib[2]

[1] Universiti Kebangsaan Malaysia, Malaysia
[2] Pantai Hospital Ayer Keroh, Malaysia

ARTICLE INFO

Article history
Received: March 20, 2025
Accepted: July 26, 2025
Available online: May 20, 2026

Keywords
Quality of life
Exoskeleton
Stroke rehabilitation
Assistive robotics

Doi
https://doi.org/10.31648/paom/208673

ABSTRACT

Introduction: Lower limb exoskeletons (LLEs) are a potential new development in assistive technology and rehabilitation that offer mechanical support and help people with lower limb limitations, such as stroke survivors. However, little is known about the effects of using an LLE on the overall lower limb functions or the psychosocial well-being of stroke survivors.

Aim: To summarise the effects of using an LLE on lower limb function, including mobility and functional independence in activities of daily living, as well as the psychosocial well-being among stroke survivors.

Material and methods: The search for this review was conducted from January 2016 to February 2024 using the following databases: MEDLINE AND OVID, SCIENCE DIRECT, PROQUEST, and EBSCOhost. The following keywords were used [(lower limb exoskeleton OR lower extremities exoskeleton OR robotic leg)] AND [(lower limb function OR lower extremities function OR leg function)] AND [(psychosocial wellbeing OR mental health OR psychological)] AND [(stroke survivors OR stroke patients)]. A total of 7 articles were included in the review.

Results and discussion: The lower limb functions were measured using several assessment tools, such as the Fugl-Meyer Assessment for Lower Extremities, Barthel Index, Modified Barthel Index, Functional Ambulation Category, and the Modified Rankin Scale. The psychosocial aspects were measured using the Mini-Mental State Examination, Stroke Impact Scale, and Stroke Specific Quality of Life Questionnaire. Improvements were observed in each paper, although some studies showed no significant difference.

Conclusions: The use of the LLE in stroke survivors during interventions has been shown to positively affect lower limb functions and the psychosocial well-being of the user.

Corresponding author: Deepashini Harithasan; Universiti Kebangsaan Malaysia,
Jalan Raja Muda Abdul Aziz, 50300, Kuala Lumpur, Malaysia.
E-mail address: deepa@ukm.edu.my

1. INTRODUCTION

Lower limb exoskeletons (LLE) have emerged as a promising technology in rehabilitation and assistive devices. An exoskeleton, also known as a robotic suit or exo-suit, is a rigid structure that supports the user's weight to aid the user with a high amount of assistance to stimulate movement such as walking.[1,2] Since the 1990s, the usage of robot assistance has become available in the rehabilitation field and is widely accepted.[3] They provide mechanical support and assistance to individuals with lower limb impairments, enabling them to regain mobility and perform activities of daily living more independently.[4] While it has been used primarily for spinal cord injury and other neurological conditions, recent studies have demonstrated its potential to improve mobility and function in stroke survivors.[5,6]

As stroke survivors retain neurological and motor deficits, they may experience difficulties in walking with average speed and patterns, having trouble in stair negotiations as it requires higher physical functions and is unsafe for community-dwelling activities.[1,7,8] These complications will contribute to a high risk of falls among them, thus reducing their confidence level and quality of life.[7,9,10] The LLE is a wearable device that utilises robotic technology to support and assist the lower limbs during movement, providing excellent stability and control for individuals who have suffered a stroke.[11] Studies have demonstrated improvements in walking speed, stride length, balance, and overall functional independence among stroke survivors who have used lower limb exoskeletons as part of their rehabilitation treatment.[12] These findings highlight the potential of lower limb exoskeletons as an effective adjunct to traditional rehabilitation in stroke rehabilitation. Aside from its physical functions and performance benefits, the exoskeleton provides satisfaction and confidence and can increase user motivation.

Current stroke rehabilitation guidelines recommend early involvement in repetitive, task-oriented, and intensive training for stroke survivors.[7,10,11] In particular, task-oriented training is the preferred approach to enhance motor function, mobility, and walking ability, which can be facilitated through the use of a lower limb exoskeleton (LLE). However, much is still to be learned about this technology's long-term efficacy and safety and its potential impact on other aspects of stroke rehabilitation. Further research is needed to fully understand the benefits and limitations of the LLE in improving functional outcomes for stroke survivors.

2. AIM

This review aims to evaluate the effects of a Lower Limb Exoskeleton (LLE) on lower limb function, including mobility and functional independence in activities of daily living, as well as assessing the psychosocial well-being among stroke survivors.

3. MATERIAL AND METHODS

3.1. Search strategies

The search for this review was conducted from January 2016 to February 2024 using the following databases: MEDLINE AND OVID, SCIENCE DIRECT, PROQUEST, and EBSCOhost. The keywords used in this literature search were [lower limb exoskeleton OR lower extremities exoskeleton OR robotic leg] AND [lower limb function OR lower extremities function OR leg function NOT upper] AND [psychosocial wellbeing OR mental health OR psychological] AND [stroke survivors OR stroke patients]. Figure 1 shows the flowchart of the process.

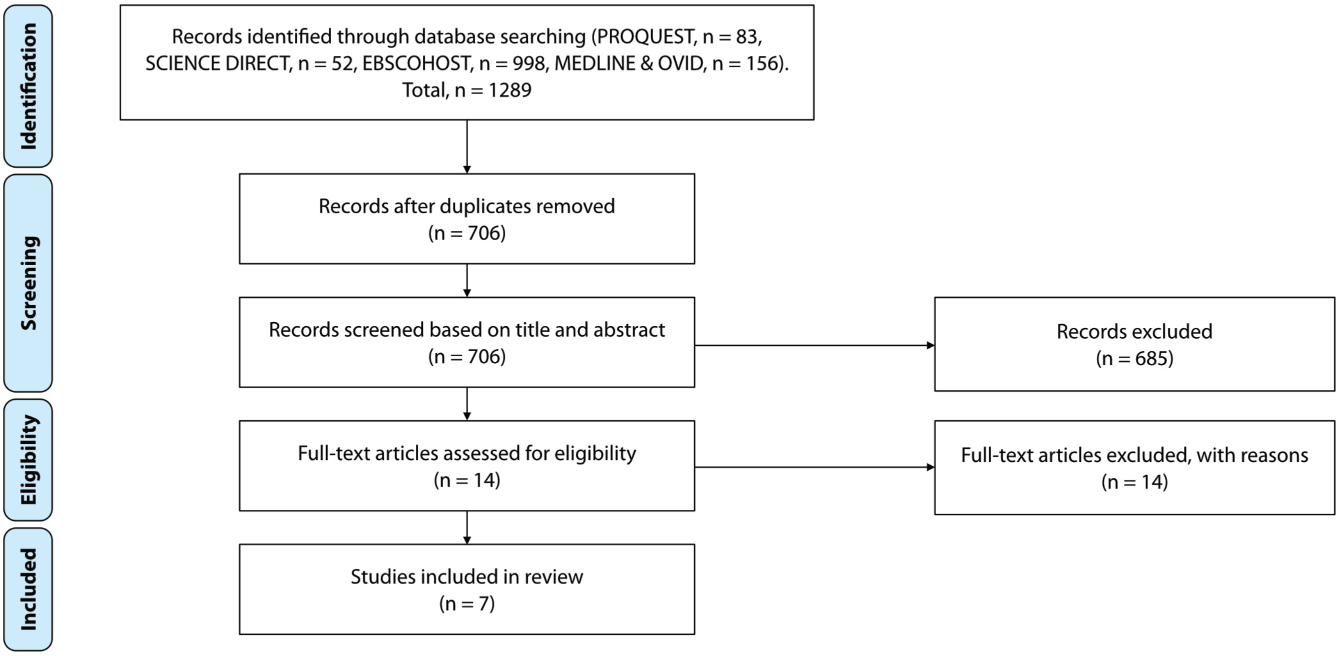

Figure 1. Shows the flowchart of the method.

3.2. Inclusions and exclusions criteria

Articles were included if they met the following criteria: they were a randomised control study, had stroke survivors of any type as participants, used a lower limb exoskeleton in the treatment regime, measured the functions of the lower limb as the primary or secondary outcome measure, and assessed the effects on the psychological well-being upon using the lower limb exoskeleton. Also, only English-language articles were included in this search.

The following items were excluded: all review articles, non-stroke survivors as participants, such as those with traumatic brain injuries, other neurological disorders, paediatrics, or healthy adults, and the usage of other exoskeletons, such as upper limb exoskeletons.

3.3. Data extraction

A list of articles was identified, and a full-article search was conducted. The reviewers (A.W. and D.H.) independently screened the titles and abstracts from the initial search to identify the eligible studies. Full-text articles were examined to see whether inclusion in this review paper was appropriate based on the inclusion and exclusion criteria.

4. RESULTS

4.1. Lower limb functions after treatment with an exoskeleton

Throughout the search, seven articles were found. Of these, 5 used Fugl-Meyer Lower Extremities (LE-FM),[3,5,8,13,15] 3 used the Barthel Index (BI),[2,3,10] 1 used the Modified Barthel Index (MBI),[5] 4 used the Functional Ambulation Category (FAC),[2,3,5,8] and 1 used the Modified Rankin Scale (MRS)[5] to assess the lower limb functions. Studies had also used multiple interventions to assess lower limb functions as well. For example, a study by Watanabe et al. 2020 used three interventions.

4.2. Psychosocial well-being after treatment with an exoskeleton

In assessing psychosocial well-being, 2 articles were found that used the mental State Examination (MMSE)[5,15] and 1 article each used the Stroke Impact Scale (SIS)[2] and Stroke Specific Quality of Life Questionnaire (SSQoL).[13] Table 1 and Table 2 show the results classified by the outcome measures.

5. DISCUSSION

Lower limb function is one of the main criteria that will be examined when managing stroke patients. The most common measured variables in research are gait-related components such as walking speed, endurance, and pattern. Meanwhile, assessing mental health and psychosocial well-being is not a priority. All studies were from outpatient settings of hospitals or private rehabilitations, and all the patients were in subacute and chronic stroke stages.

As shown in Table 1, positive improvements were observed in the within-group analysis. Most outcome measures showed significant improvement in pre/post-treatment. The study's strengths include its focus on comparing the effectiveness of technology-assisted rehabilitation to traditional rehabilitation for stroke patients. The study's findings suggest that technology-assisted rehabilitation can be as effective as traditional rehabilitation, sometimes even better for stroke patients, presenting a more cost- and labour-efficient option for countries with scarce clinical resources and funding. In a study by Bustamante et al. 2016, the within-group analysis showed that both groups improved the LE-FM scores post-intervention.[15] However, the IG showed a significantly more significant improvement in the LE-FM scores compared to the CG, with the change in IG, on average, at 2.8 change points greater than the CG. Additionally, the effect size showed that the intervention had a moderate effect (0.59) on LE-FM outcomes and little to no effect on the CG (0.08). Similar results can be seen in studies done by Watanabe et al. 2020, Kim et al. 2019 and Kim et al. 2016. A similar study, which involved 1472 participants, was reported in a Cochrane review. It showed that combining the technology behind the lower limb exoskeleton with physiotherapy interventions can increase the chances for the participants to engage in independent walking.[14] This suggests that robot-assisted gait training combined with conventional physical therapy may improve the gait ability of the affected lower extremity compared to conventional physical therapy alone.

However, most of the between-group analyses showed no significant improvement. This may be due to the differences in rehabilitation protocol between the two groups and the human-robot interaction. For instance, in the Kim et al. 2019 study, IG underwent robot-assisted gait training combined with conventional physical therapy, whereas the CG underwent conventional physical therapy (CPT) only. Unlike other studies, such as Watanabe et al. 2020, Morone et al. 2016 and Bustamante Valles et al. 2016, the IG performed therapy sessions using the robot, and CG received conventional gait training. The differences in rehabilitation protocol, such as duration and intensity of training with the robot and therapist, may lead to different recovery trajectories. Also, combining robotic and conventional training or relying solely on robotic assistance or conventional rehabilitation may cause differences in the outcome. In studies involving conventional rehabilitation, the level of therapist involvement may also be a factor that may influence the results. This may be because the interventions may include active guidance from therapists, while others rely solely on the robotic device. Other factors may be individual differences in how quickly patients adapt to the robotic systems, impacting how well they respond to therapy. Some devices require more familiarisation and training than others. Also, the level of patient motivation and how actively they engage with the robotic device may also vary, impacting the effectiveness of the intervention. A previous research study found that using a robotic device during gait training led to an increase in motor output, engagement, and motivation among patients.[16]

Table 1. Outcome measures used to assess lower limb functions of patients after treatment with an exoskeleton.

Outcome measures used to assess lower limb functions after treatment with exoskeleton			
Researcher(s)	Outcome measures	Participants	Findings
Bustamante Valles KB, et al. 2016	LE-FM	n = 20 (IG = 10, CG = 10). Randomly allocating ten patients to each group (Robot Gym vs control).	The between-group analysis of LE-FM showed no significant differences pre-intervention ($p = 0.28$). However, post-intervention, the intervention group (IG) improved by an average of 2.8 points more than the control group (CG) (**$p < 0.05$**). Within-group analysis revealed a significant improvement in IG (average increase of 3.3 points, **$p < 0.05$**), while CG showed minimal progress (0.5 points, $p > 0.05$). These results suggest that Robot Gym therapy significantly enhanced lower extremity function.
Chua J, et al. 2016	BI FAC	n = 106 (IG: 53, CG: 53). Random allocation to electromechanical gait trainer (IG) and physiotherapy groups (CG).	There was a significant improvement over time ($p < 0.05$), but no group or group × time effects were found. Both BI and FAC improved significantly in all patients, with no differences between groups, suggesting both treatments were equally effective in enhancing functional independence and ambulation post-stroke.
Jayaraman A, et al. 2019	LE-FM	n = 50 (IG:25, CG:25). Randomized, single-blind, parallel study design, Gait training with Honda Stride Management Assist exoskeleton (IG) vs functional training (CG).	LE-FM showed significant improvements from pre-treatment to all time points ($p < 0.05$), with a mean difference of 6.3 ± 2.4 higher post-treatment in IG. These results highlight the effectiveness of IG in enhancing lower extremity function in stroke survivors.
Kim HY, et al. 2019	LE-FM	n = 19 (IG: 10, CG:9). Random allocation to robot-assisted gait training + conventional physical therapy (IG) and conventional physical therapy alone (CG).	Significant between- and within-group differences in LE-FM were observed (**$p < 0.05$**), with IG showing greater improvement (mean difference: 2.35 ± 0.42). This suggests that robot-assisted gait training effectively enhances stroke recovery.
	FAC		No significant differences were found between groups ($p = 0.14$) or within CG ($p = 0.16$) for FAC. However, IG showed significant improvement (**$p < 0.05$**) with a mean difference of 0.53 ± 0.11, suggesting the potential of robot-assisted gait training in enhancing balance and stability in stroke patients.
Kim SJ, et al. 2016	LE-FM MBI FAC	n = 38 (IG). Prospective trial with 40 training sessions.	Significant pre-to-post treatment differences were observed (**$p < 0.05$**), with higher post-treatment scores (LE-FM: 2.84 ± 1.44, MBI: 14.56 ± 2.84, FAC: 1.18 ± 0.33). These findings highlight the effectiveness of robot-assisted gait training in improving walking ability in non-ambulatory stroke patients.
	MRS		Significant differences were observed (**$p < 0.05$**), with a post-treatment decrease in MRS score (mean difference: 0.56 ± 0.07), indicating improved independence and reduced disability.
Morone G, et al. 2016	BI	n = 44 (IG: 22, CG: 22). Random assignment to i-Walker group (IG) and control group (CG).	Clinical BI scores were close to the statistically significant threshold ($p = 0.076$). The study highlights the potential benefits of robotic-assisted therapy in enhancing balance and possibly improving daily living activities.
Watanabe H, et al. 2020	LE-FM	n = 22 (IG:12, CG:10). Non-randomized clinical trial.	No significant between-group difference in LE-FM was found ($p = 0.87$), but both IG and CG showed significant pre-to-post treatment improvements (**$p < 0.05$**), with mean differences of 8.00 ± 2.5 and 1.5 ± 2, respectively. This highlights the benefits of both treatment approaches in post-stroke rehabilitation.
	BI		No significant between-group difference in BI was found ($p = 0.54$), but both groups showed significant pre-to-post treatment improvements (**$p < 0.05$**). IG had greater improvement (22.5 ± 5.0) compared to CG (10.0 ± 10.0), indicating both interventions enhanced functional independence in stroke patients.
	FAC		A significant between-group difference in FAC (**$p < 0.05$**) showed IG had higher scores than CG, demonstrating the intervention's superior effectiveness in promoting independent walking in stroke patients.

Comment: LE-FM – Fugl-Meyer Lower Extremities Assessment; BI – Barthel Index; MBI – Modified Barthel index; FAC – Functional Ambulation Category; MRS – Modified Rankin Scale; pre-treatment – assessment done before starting the treatment without exoskeleton usage; post-treatment – assessment taken after undergone treatment with exoskeleton usage; CG – Control Group; IG – Intervention Group.

Table 2. Outcome measures used to assess the psychosocial well-being of patients after treatment with an exoskeleton.

Outcome measures used to assess the psychosocial well-being of patients after treatment with an exoskeleton			
Researcher(s)	Outcome measures	Participants	Outcome
Bustamante Valles KB, et al. 2016	MMSE	n = 20 (IG = 10, CG = 10)	No significant changes were observed ($p = 0.41$), indicating similar cognitive abilities in both groups.
Chua J, et al. 2016	SIS	n = 106 (IG: 53, CG: 53)	A significant improvement over time ($p < 0.05$) indicated better participation in daily activities, but no group differences were found, suggesting both groups equally improved the quality of life for stroke survivors.
Jayaraman A, et al. 2019	SSQoL	n = 50 (IG:25, CG:25)	A significant change from pre-treatment to all other time points ($p < 0.05$) indicates improvements in functional outcomes that could enhance quality of life.
Kim SJ, et al. 2016	MMSE	n = 38 (IG)	No significant changes were observed ($p > 0.05$), suggesting that while the training may improve physical capabilities, it does not necessarily enhance cognitive function.

Comment: MMSE – Mini-Mental State Examination; SIS – Stroke Impact Scale; SSQoL – Stroke Specific Quality of Life Questionnaire; pre-treatment – assessment done before starting the treatment without exoskeleton usage; post-treatment – assessment taken after undergoing treatment with exoskeleton usage; CG – Control Group; EG – Experimental Group.

Only four out of 7 studies assessed the patients' psychosocial well-being and two significantly improved the within-group comparisons. The outcome measures were MMSE, SIS, and SSQoL. The MMSE did not show a significant change after robot training in the study.[5,15] However, the SIS memory and thinking scores showed improvement over time for both groups.[2] Similarly, the exoskeleton group showed an improvement of 4.6 (SD 9.2) in SSQoL scores, and the functional training group demonstrated an improvement of 3.0 (SD 11.5) in SSQoL scores after the assessment. These improvements may encompass physical, emotional, social, and cognitive domains affected by stroke, reflecting a positive change in how the patients perceive and experience their quality of life post-intervention. The increase in SSQoL scores signifies a potential enhancement in overall well-being and satisfaction with life following the gait training interventions.[13]

The lack of significant improvement in the MMSE scores implies that cognitive function may not have been positively affected by the robot-assisted gait training within the study's timeframe. This could indicate that cognitive rehabilitation may require different approaches or more time to see improvements. One possible reason may be due to the focus of the intervention. The robot-assisted gait training in the study may have primarily targeted physical aspects of rehabilitation, such as gait function and motor recovery, rather than cognitive function assessed by the MMSE. Other than that, the characteristics of the patients may have had relatively stable cognitive function at baseline, leading to minimal changes in MMSE scores throughout the intervention. The duration and intensity of the robot training sessions may not have been sufficient to produce noticeable improvements in cognitive function as measured by the MMSE. Other than that, the MMSE may not be sensitive enough to detect subtle changes in cognitive function that could result from the specific type of intervention provided in the study. Also, cognitive function can vary widely among stroke patients, and some individuals may not show significant changes in MMSE scores even with interventions targeting physical rehabilitation.

As the studies examining psychosocial well-being are minimal, more studies are needed to explore the benefits of robotics in influencing cognitive function.[16] Future studies can consider several strategies to address the factors contributing to cognitive function after robot training in stroke patients. One such way is incorporating a multidisciplinary approach that includes cognitive rehabilitation techniques alongside physical rehabilitation. This can involve cognitive training exercises, memory tasks, attention exercises, and problem-solving activities to target cognitive function directly. Customising the robot-assisted gait training program to include cognitive tasks or dual-task training that challenges cognitive functions while engaging in physical activities will also be beneficial. This dual-task training can help improve cognitive-motor interactions and potentially enhance cognitive outcomes. Increasing the duration and intensity of the intervention sessions to provide more comprehensive cognitive stimulation is another strategy to consider. Longer and more frequent training sessions may lead to more significant cognitive improvements. Combining cognitive assessment tools to capture a broader range of cognitive functions, such as executive function, attention, memory, and processing speed, can provide a more nuanced understanding of cognitive changes following the intervention. Finally, long-term follow-up assessments should be implemented to track cognitive changes beyond the immediate post-intervention period. This can help evaluate the sustainability of cognitive improvements and identify any delayed effects of the intervention. By incorporating these strategies, researchers and clinicians can potentially enhance the cognitive outcomes of robot-assisted gait training in stroke patients.

6. CONCLUSIONS

Lower limb function is vital in stroke rehab, with tech-assisted gait therapy showing promise. Integrating cognitive rehab into robotic training may improve outcomes, supporting a multidisciplinary approach.

Ethics approval

None declared.

Conflict of interest

None declared.

Funding

None declared.

Author Contributions

Study design: DH
Data collection: AMN
Statistical analysis: DH, AMN
Data interpretation: DH
Manuscript preparation: DH
Literature search: AMN

References

1. Awad LN, Bae J, O'Donnell K, et al. A soft robotic exosuit improves walking in patients after stroke. *Sci Transl Med.* 2017;9(400). https://doi.org/10.1126/scitranslmed.aai9084.
2. Chua J, Culpan J, Menon E. Efficacy of an Electromechanical Gait Trainer Poststroke in Singapore: A Randomized Controlled Trial. *Arch Phys Med Rehabil.* 2016;97(5):683–690. https://doi.org/10.1016/j.apmr.2015.12.025.
3. Watanabe H, Marushima A, Kadone H, et al. Effects of Gait Treatment With a Single-Leg Hybrid Assistive Limb System After Acute Stroke: A Non-randomized Clinical Trial. *Front Neurosci.* 2020;13(January):1–10. https://doi.org/10.3389/fnins.2019.01389.
4. Plaza A, Hernandez M, Puyuelo G, Garces E, Garcia E. Lower-limb medical and rehabilitation exoskeletons: A review of the current designs. *IEEE Rev Biomed Eng.* 2021;16:278–291.
5. Kim SJ, Lee HJ, Hwang SW, et al. Clinical characteristics of proper robot-assisted gait training group in non-ambulatory subacute stroke patients. *Ann Rehabil Med.* 2021;40(2):183–189. https://doi.org/10.5535/arm.2016.40.2.183.
6. Korczyński B, Beata T. Polysomnography in patients with spinal cord injury who underwent robotic assisted gait training. *Pol Ann Med.* 2023;30(2):114–120. https://doi.org/10.29089/ paom/175360.
7. Bannwart M, Rohland E, Easthope CA, Rauter G, Bolliger M. Robotic body weight support enables safe stair negotiation in compliance with basic locomotor principles. *J Neuroeng Rehabil.* 2019;16(1):1–15. https://doi.org/10.1186/s12984-019-0631-8.
8. Kim HY, Shin JH, Yang SP, Shin MA, Lee SH. Robot-assisted gait training for balance and lower extremity function in patients with infratentorial stroke: A single-blinded randomized controlled trial. *J Neuroeng Rehabil.* 2019;16(1):1–12.
9. Mikolajczyk T, Ciobanu I, Badea DI, et al. Advanced technology for gait rehabilitation: An overview. *Adv Mech Eng.* 2018;10(7):1–19. https://doi.org/10.1177/1687814018783627.
10. Morone G, Annicchiarico R, Iosa M, et al. Overground walking training with the i-Walker, a robotic servo-assistive device, enhances balance in patients with subacute stroke: A randomized controlled trial. *J Neuroeng Rehabil.* 2019;13(1):1–10. https://doi.org/10.1186/s12984-016-0155-4.
11. Louie DR, Mortenson WB, Durocher M, Teasell R, Yao J, Eng JJ. Exoskeleton for post-stroke recovery of ambulation (ExStRA): Study protocol for a mixed-methods study investigating the efficacy and acceptance of an exoskeleton-based physical therapy program during stroke inpatient rehabilitation. *BMC Neurol.* 2019;20(1):1–9. https://doi.org/10.1186/s12883-020-1617-7.
12. Baker R, Esquenazi A, Benedetti MG, Desloovere K. Gait analysis: Clinical facts. *Eur J Phys Rehabil Med.* 2016;52(4):560–574.
13. Jayaraman A, O'Brien MK, Madhavan S, et al. Stride management assist exoskeleton vs functional gait training in stroke: A randomized trial. *Neurol.* 2019;92(3):263–273. https://doi.org/10.1212/WNL.0000000000006782.
14. Erbil D, Tugba G, Murat TH, et al. Effects of robot-assisted gait training in chronic stroke patients treated by botulinum toxin-a: A pivotal study. *Physiother Res Int.* 2018;23(3):1–8. https://doi.org/10.1002/pri.1718.
15. Bustamante Valles K, Montes S, Madrigal MDJ, Burciaga A, Martínez ME, Johnson MJ. Technology-assisted stroke rehabilitation in Mexico: A pilot randomized trial comparing traditional therapy to circuit training in a Robot/technology-assisted therapy gym. *J Neuroeng Rehabil.* 2016;13(1):1–15. https://doi.org/10.1186/s12984-016-0190-1.
16. Sung J, Choi S, Kim H, et al. Feasibility of rehabilitation training with a newly developed, portable, gait assistive robot for balance function in hemiplegic patients. *Ann Rehabil Med.* 2017;41(2):178–187. https://doi.org/10.5535/arm.2017.41.2.178.