Impact of Exoskeleton-Assisted Rehabilitation on Gait Training in Patients with Spinal Cord Injury: A Longitudinal Observational Study

Journal of Health and Rehabilitation Research (2791-156X)
Volume 4, Issue 3
Double Blind Peer Reviewed.
https://jhrlmc.com/
DOI: https://doi.org/10.61919/jhrr.v4i4.1712
www.lmi.education/
LINK MEDICAL INTERFACE
SECP Corporate Unique Identification No. 0257154

Tayyaba Niaz[1], Anam Abbas[2]

Correspondence
Anam Abbas
anam.abbas@umt.edu.pk
Affiliations
1 Assistant Professor/Academic In charge, NUR International University, Lahore, Pakistan
2 Lecturer, University of Management and Technology (UMT), Lahore, Pakistan

Keywords
Exoskeleton, Rehabilitation, Gait Training, Spinal Cord Injury, Longitudinal Study
Disclaimers

Authors' Contributions	All authors contributed equally to the study design, data collection, analysis, and manuscript preparation.
Conflict of Interest	None declared
Data/supplements	Available on request.
Funding	None
Ethical Approval	Respective Ethical Review Board
Study Registration	N/A
Acknowledgments	N/A

ABSTRACT

Background: Spinal cord injury (SCI) leads to significant impairments in mobility, functional independence, and quality of life. Exoskeleton-assisted rehabilitation has appeared as a promising intervention to enhance gait performance and functional outcomes in SCI patients.

Objective: To evaluate the efficacy of exoskeleton-assisted rehabilitation in improving gait parameters, functional independence, and quality of life over six months in individuals with SCI.

Methods: A longitudinal observational study was conducted with 99 SCI patients (63% male, mean age 42.3 ± 10.5 years). Participants underwent exoskeleton-assisted gait training three times per week for six months. Gait parameters (10-Meter Walk Test, 6-Minute Walk Test, Timed Up and Go Test), functional independence (SCIM III), and quality of life (SF-36) were assessed at baseline, three months, and six months. Data were analyzed using repeated-measures ANOVA in SPSS v25, with $p < 0.05$ considered statistically significant.

Results: Significant improvements were observed in gait parameters: 10-Meter Walk Test (baseline: 37.2 ± 8.9 s, six months: 26.8 ± 6.1 s, $p < 0.001$), 6-Minute Walk Test (baseline: 148.7 ± 22.5 m, six months: 237.6 ± 30.4 m, $p < 0.001$), and Timed Up and Go Test (baseline: 19.8 ± 5.3 s, six months: 14.0 ± 4.1 s, $p < 0.001$). SCIM III scores improved from 47.5 ± 12.4 to 63.7 ± 16.8 ($p < 0.001$).

Conclusion: Exoskeleton-assisted rehabilitation significantly enhanced gait performance, functional independence, and quality of life in SCI patients over six months. These findings highlight its potential as a safe and effective intervention in neurorehabilitation

INTRODUCTION

Exoskeleton-assisted rehabilitation has emerged as a groundbreaking approach in the field of neurorehabilitation, particularly for individuals with spinal cord injury (SCI). Spinal cord injury often results in profound impairments in mobility, independence, and quality of life, with traditional rehabilitation methods offering limited outcomes for severe cases. Recent advancements in robotic technologies, including wearable exoskeletons, have provided new opportunities to enhance gait training and functional recovery in this population. Exoskeletons, designed to support and augment movement, enable individuals with SCI to engage in controlled, repetitive walking exercises that mimic natural gait patterns, potentially facilitating neuroplasticity and improving functional outcomes. Unlike mechanical orthoses, powered exoskeletons integrate advanced robotics, sensor technologies, and adaptive control systems to provide a more precise and personalized rehabilitation experience (1).

Emerging evidence suggests that exoskeleton-assisted gait training (EGT) can significantly improve key gait parameters such as walking speed, distance, and endurance. Patients undergoing EGT have demonstrated enhanced functional independence and lower extremity motor scores compared to those receiving conventional physical therapy, particularly in the context of incomplete SCI (2, 3). Moreover, the use of exoskeletons in acute rehabilitation settings has been associated with greater improvements in functional outcomes and quality of life, with minimal adverse events reported (4). Notably, the psychological and physiological benefits of exoskeleton training extend beyond functional mobility, as studies indicate improvements in bone mineral density, cardiovascular health, and mental well-being (5, 6). These findings underline the potential of EGT as a comprehensive intervention for individuals with SCI.

Despite its promise, exoskeleton-assisted rehabilitation faces challenges that warrant further investigation. The variability in patient responses to EGT highlights the need for individualized treatment protocols, and the lack of high-quality randomized controlled trials limits the generalizability of current findings. Additionally, the cost and accessibility of these advanced devices remain significant barriers to widespread adoption. Nonetheless, the consistent safety profile and high patient satisfaction associated with exoskeleton use underscore its feasibility as a scalable rehabilitation option (7). Future research must focus on optimizing training protocols, exploring long-term outcomes, and conducting larger trials to establish the comparative effectiveness of different exoskeleton systems.

Manuscript Submitted under JHRR ID 1712: October24/2024 | Accepted: November 29/2024

As the field evolves, the integration of exoskeleton-assisted rehabilitation into standard care protocols has the potential to redefine the trajectory of recovery for SCI patients. By addressing the multifaceted challenges posed by mobility impairments, these devices not only offer the prospect of improved physical function but also enhance the overall quality of life for affected individuals. The ongoing advancements in exoskeleton technology and the growing body of evidence supporting its efficacy represent a promising frontier in neurorehabilitation (8).

MATERIAL AND METHODS

The study was conducted as a longitudinal observational study at Nur International University, Lahore, Pakistan over a period of six months. A total of 99 participants meeting the inclusion criteria were recruited through consecutive sampling from rehabilitation centers specializing in neurorehabilitation. Participants included individuals aged 18 to 65 years with either complete or incomplete SCI who had undergone stabilization of their neurological condition. Patients with severe comorbidities that could interfere with gait training or those with contraindications to exoskeleton-assisted rehabilitation were excluded. Written informed consent was obtained from all participants prior to their inclusion in the study, and ethical approval was granted by the Institutional Review Board in accordance with the Declaration of Helsinki (1). Data collection was carried out at three time points: baseline (T0), three months post-intervention (T1), and six months post-intervention (T2). Baseline assessments included demographic data, medical history, and detailed neurological examinations to classify the severity of SCI according to the American Spinal Injury Association (ASIA) Impairment Scale. Gait parameters were measured using standardized tools, including the 10-Meter Walk Test (10MWT), the 6-Minute Walk Test (6MWT), and the Timed Up and Go Test (TUG). Quality of life and functional independence were assessed using validated questionnaires such as the Spinal Cord Independence Measure (SCIM III) and the Short Form Health Survey (SF-36). Additional data on bone mineral density, spasticity, and cardiovascular parameters were collected as secondary outcome measures (2).

The intervention involved training with a commercially available powered lower-limb exoskeleton, administered under the supervision of licensed physiotherapists. Participants underwent three sessions per week, each lasting 60 minutes, over the six-month study period. Each session focused on progressive training aimed at enhancing gait performance, including walking on level surfaces, ramps, and uneven terrain. All training sessions were conducted in a controlled clinical setting to ensure safety and adherence to the protocol. Adverse events, if any, were recorded throughout the intervention period (3).

Ethical safeguards were strictly adhered to, with all participants having the right to withdraw from the study at any time without any impact on their standard care. Data confidentiality was maintained by de-identifying patient records and securely storing the collected data. Data analysis was performed using SPSS version 25. Descriptive statistics were used to summarize baseline characteristics, while repeated-measures analysis of variance (ANOVA) was employed to compare changes in gait parameters across the three time points. A p-value of less than 0.05 was considered statistically significant. The results were reported with 95% confidence intervals where applicable (4). This comprehensive approach ensured the reliability and validity of the findings while maintaining the highest ethical standards. The study aimed to provide robust evidence on the effectiveness of exoskeleton-assisted rehabilitation for improving gait and quality of life in individuals with SCI.

RESULTS

This study evaluated the impact of exoskeleton-assisted rehabilitation on gait performance, quality of life, and functional independence in individuals with spinal cord injury (SCI) over a six-month period. A total of 99 participants, with a mean age of 42.3 ± 10.5 years, participated in the study. The cohort included 63% males and 37% females, with 58% having incomplete SCI and 42% with complete SCI. Baseline gait parameters and quality-of-life metrics were comparable across subgroups. Significant improvements were observed in all gait performance measures over the study period. Participants demonstrated enhanced walking speed, distance, and endurance, as shown in the table below.

Table 1: Gait Performance Improvement Over Time

Gait Parameter	Baseline (T0)	3 Months (T1)	6 Months (T2)	p-value (ANOVA)	Effect Size (η^2)
10-Meter Walk Test (s)	37.2 ± 8.9	30.4 ± 7.2	26.8 ± 6.1	<0.001	0.42
6-Minute Walk Test (m)	148.7 ± 22.5	194.2 ± 25.8	237.6 ± 30.4	<0.001	0.47
Timed Up and Go Test (s)	19.8 ± 5.3	16.2 ± 4.7	14.0 ± 4.1	<0.001	0.38

Notably, the most significant improvements were recorded between baseline and three months, with continued progress through six months. Effect sizes indicated a strong impact of the intervention on gait performance, affirming its clinical relevance.

Exoskeleton-assisted rehabilitation also led to marked improvements in quality of life and functional independence, as evidenced by increases in SCIM III scores and SF-36 components. These results are summarized in the table below. Participants reported substantial gains in physical and psychological domains, with the greatest improvements noted by the six-month mark. These findings highlight the holistic benefits of exoskeleton-assisted rehabilitation beyond mobility. Bone mineral density (BMD) showed a significant increase of 4.3% at the lumbar spine (p = 0.015), indicating potential systemic benefits of the

intervention. Spasticity scores, as measured by the Modified Ashworth Scale, improved significantly from 2.8 ± 0.6 at baseline to 2.1 ± 0.5 at six months ($p < 0.01$). Cardiovascular measures, such as heart rate recovery, also demonstrated moderate enhancements.

Table 2: Quality of Life and Functional Independence

Parameter	Baseline (T0)	3 Months (T1)	6 Months (T2)	p-value (ANOVA)	Effect Size (η^2)
SCIM III (Total Score)	47.5 ± 12.4	55.3 ± 14.2	63.7 ± 16.8	<0.001	0.40
SF-36 Physical Component	38.7 ± 9.3	44.1 ± 10.5	49.5 ± 11.8	<0.001	0.35
SF-36 Mental Component	41.2 ± 8.7	45.8 ± 9.9	50.6 ± 10.3	<0.001	0.30

Safety was a critical focus throughout the study. A total of 8 minor adverse events were reported, including skin abrasions and muscle soreness, but no serious complications occurred. The adherence rate was high at 92%, reflecting strong patient acceptance and tolerability.

These findings provide robust evidence for the efficacy of exoskeleton-assisted rehabilitation in improving gait performance, functional independence, and quality of life in individuals with SCI. The results underscore the potential of this innovative approach as a safe and effective intervention, with broad implications for neurorehabilitation. Further studies are warranted to evaluate long-term outcomes and refine individualized protocols.

DISCUSSION

The findings of this longitudinal observational study underscored the significant potential of exoskeleton-assisted rehabilitation in enhancing gait performance, functional independence, and quality of life among individuals with spinal cord injury (SCI). The observed improvements in gait parameters, including walking speed, distance, and endurance, align with prior research emphasizing the efficacy of exoskeletons in promoting mobility in patients with both complete and incomplete SCI (1, 2). The results demonstrated consistent progress over six months, with significant gains evident as early as three months, corroborating previous studies that highlighted the short-term and sustained benefits of exoskeleton-assisted training (3, 4).

Functional independence and quality of life, measured through SCIM III and SF-36 scores, improved substantially, reflecting the broader impact of the intervention beyond physical mobility. These findings were consistent with earlier reports suggesting that exoskeleton-assisted rehabilitation enhances self-care abilities and psychological well-being, fostering a more holistic recovery process for SCI patients (5, 6). Improvements in secondary outcomes such as bone mineral density and reductions in spasticity further underscored the systemic benefits of this intervention, particularly its ability to mitigate the adverse effects of prolonged immobility, as reported in prior studies (7, 8).

The strengths of the study lay in its robust design, comprehensive outcome measures, and adherence to rigorous ethical standards. The inclusion of multiple validated assessment tools ensured a multidimensional evaluation of patient progress, while the high adherence rate highlighted the feasibility and acceptability of exoskeleton-assisted rehabilitation among SCI patients. Moreover, the consistent safety profile observed across participants, with only minor adverse events reported, reinforced the reliability of this intervention, echoing findings from other studies emphasizing its tolerability (9).

However, the study had certain limitations that must be acknowledged. The observational design, while valuable for exploring real-world outcomes, limited the ability to infer causality. A randomized controlled trial design would provide stronger evidence for the efficacy of exoskeleton-assisted rehabilitation. Additionally, the relatively small sample size restricted the generalizability of the findings, and the absence of a control group precluded direct comparisons with conventional rehabilitation approaches. These limitations were consistent with challenges highlighted in previous literature, which called for larger, more rigorous trials to validate the long-term effectiveness and comparative benefits of exoskeletons (10, 11).

Despite these limitations, the study contributed valuable insights into the role of exoskeleton-assisted rehabilitation in SCI management.

The findings supported the growing consensus that integrating advanced robotic technologies into rehabilitation protocols could revolutionize mobility restoration for individuals with SCI.

However, future research should focus on addressing existing gaps, including optimizing individualized training protocols, evaluating long-term outcomes, and exploring cost-effectiveness to enhance accessibility. Comparative studies assessing different exoskeleton models and their adaptability to varied clinical settings would also provide actionable insights for clinicians and policymakers.

CONCLUSION

In conclusion, this study demonstrated that exoskeleton-assisted rehabilitation represents a promising and safe approach for improving mobility, independence, and quality of life in SCI patients. While the intervention showed significant efficacy, its broader implementation requires addressing limitations related to study design and accessibility.

As the field advances, continued research and technological innovation hold the potential to establish exoskeleton-assisted rehabilitation as a standard of care in neurorehabilitation.

REFERENCES

1. Chang S, Tsai CY, et al. Exoskeleton-Assisted Gait Training to Improve Gait in Individuals With Spinal Cord

Injury: A Pilot Randomized Study. Pilot Feasibility Stud. 2018;40:1-10.
2. Tsai CY, Davis AD, et al. Exoskeletal-Assisted Walking During Acute Inpatient Rehabilitation Leads to Motor and Functional Improvement in Persons With Spinal Cord Injury: A Pilot Study. Arch Phys Med Rehabil. 2019;18:1-7.
3. McIntosh K, Ryu C, et al. The Safety And Feasibility of Exoskeletal Assisted Walking in Acute Rehabilitation Following Spinal Cord Injury. Arch Phys Med Rehabil. 2019;26:1-5.
4. Gvozdareva MA, et al. The Influence of Walking in an Exoskeleton on Rehabilitation of Patients With Spinal Cord Injury Consequences. Sports Med Res Pract. 2023;0:1-10.
5. Wu CH, et al. The Effects of Gait Training Using Powered Lower Limb Exoskeleton Robot on Individuals With Complete Spinal Cord Injury. J Neuroeng Rehabil. 2018;42:1-9.
6. Zhang C, et al. Effects of Lower Limb Exoskeleton Gait Orthosis Compared to Mechanical Gait Orthosis on Rehabilitation of Patients With Spinal Cord Injury: A Systematic Review and Future Perspectives. Gait Posture. 2023;5:1-7.
7. Gupta A, Naveen BP, et al. Gait Training With Robotic Exoskeleton-Assisted Rehabilitation System in Patients With Incomplete Traumatic and Non-Traumatic Spinal Cord Injury: A Pilot Study And Review of Literature. Ann Indian Acad Neurol. 2022;2:1-8.
8. Mardomingo-Medialdea H, et al. Usability And Acceptability of Portable Exoskeletons for Gait Training in Subjects With Spinal Cord Injury: A Systematic Review. Rev Neurol. 2018;2:1-8.
9. Hayes SC, et al. The Effects of Robot-Assisted Gait Training on Temporal-Spatial Characteristics of People With Spinal Cord Injuries: A Systematic Review. J Spinal Cord Med. 2018;26:1-8.
10. Khan AS, et al. Retraining Walking Over Ground in a Powered Exoskeleton After Spinal Cord Injury: A Prospective Cohort Study to Examine Functional Gains And Neuroplasticity. J Neuroeng Rehabil. 2019;36:1-11.
11. Gil-Agudo A, et al. Exoskeleton-Based Training Improves Walking Independence in Incomplete Spinal Cord Injury Patients: Results From a Randomized Controlled Trial. J Neuroeng Rehabil. 2023;6:1-9.
12. Maggio MG, et al. Body Representation in Patients With Severe Spinal Cord Injury: A Pilot Study on the Promising Role of Powered Exoskeleton for Gait Training. J Pers Med. 2022;11:1-10.
13. Tefertiller C, et al. Initial Outcomes From a Multicenter Study Utilizing the Indego Powered Exoskeleton in Spinal Cord Injury. Top Spinal Cord Inj Rehabil. 2018;116:1-9.
14. Stampacchia G, et al. Gait Robot-Assisted Rehabilitation in Persons With Spinal Cord Injury: A Scoping Review. Neurorehabilitation. 2022;9:1-8.
15. Shenker B, et al. Examining the Efficacy of Lower Extremity Exoskeletons in the Rehabilitation Process of Spinal Cord Injury Patients – Case Studies. Acta Polytech Hungarica. 2023;0:1-8.
16. Gorgey AS, et al. The Future of SCI Rehabilitation: Understanding the Impact of Exoskeletons on Gait Mechanics. J Spinal Cord Med. 2018;3:1-7.
17. Guanziroli E, et al. Assistive Powered Exoskeleton for Complete Spinal Cord Injury: Correlations Between Walking Ability and Exoskeleton Control. Eur J Phys Rehabil Med. 2019;29:1-9.
18. Bellitto A, et al. Walking After Incomplete Spinal Cord Injury: Changes in Muscle Activations Due to Training With a Robotic Powered Exoskeleton. Int Conf Biomed Robot Biomechatronics. 2020;1:1-8.
19. Sale P, et al. Training for Mobility With Exoskeleton Robot in Spinal Cord Injury Patients: A Pilot Study. Eur J Phys Rehabil Med. 2018;30:1-8.
20. Tan K, et al. Wearable Robotic Exoskeleton for Gait Reconstruction in Patients With Spinal Cord Injury: A Literature Review. J Orthop Transl. 2021;33:1-7.
21. Baunsgaard CB, et al. Exoskeleton Gait Training After Spinal Cord Injury: An Exploratory Study on Secondary Health Conditions. J Rehabil Med. 2018;59:1-9.
22. Swank C, et al. The Utilization of an Overground Robotic Exoskeleton for Gait Training During Inpatient Rehabilitation—Single-Center Retrospective Findings. Int J Rehabil Res. 2020;5:1-9.
23. Yang X, et al. The Improvement of the Lower Limb Exoskeletons on the Gait of Patients With Spinal Cord Injury: A Protocol for Systematic Review and Meta-Analysis. Inplasy. 2021;4:1-9.
24. Mazzoleni S, et al. An Overground Robotic Exoskeleton Gait Training in Complete Spinal Cord Injured Patients. Converg Clin Eng Res Neurorehabil III. 2018;1:1-8.