**Speed**

Gait speed is one of the most reported on outcomes in the body of research looking at robotic exoskeletons. The majority look at subjects with spinal cord injury (45 articles) followed by stroke (26 articles). Most articles were case series, though there were also a number of review articles (24) that examined gait speed. Most articles used the 10 Meter Walk Test (10MWT) to measure gait speed, with this measure being used in 72% of trials. Of studies that utilized a single device, Ekso1.1/GT/NR device, referred to as “Ekso” in this paper, was used the most (33 articles), followed by ReWalk (8) and Indego (6).

*Spinal Cord Injury (SCI)*

Like most of the research on exoskeletons, the majority of research looking at walking speed is completed with patients with SCI.

There are a few randomized controlled trials (RCTs) that examine gait speed measured outside of the exoskeleton, some of which compared exoskeletons to other treatment methods. One study randomized participants with chronic incomplete SCI to receive either Ekso (n=9), body weight support treadmill training (BWSTT) (n=10), or their normal daily activities (n=6) for 12 weeks.1 Self-selected gait speed increased by 51% in the Ekso group, 32% in the BWSTT group, and 14% in the normal activities group.1 When looking at which group had the most responders, meaning those who improved gait speed beyond the Minimal Clinically Important Difference (MCID) of 0.15 m/s, the Ekso group was victorious, with 33% reaching that metric, compared to 20% in the BWSTT group and 0% in the normal activities group.1 The other RCT compared Ekso to conventional gait training. It used seven participants with chronic motor incomplete injuries to receive treatment for 15 sessions over 3 weeks. No statistically significant difference was found between the two groups in the mean difference between pre and post assessments, however, this was complicated by significant between group differences in gait speed at baseline.2

Some studies noted improvement in gait speed outside of a device when comparing testing completed pre-exoskeleton intervention to that completed post-exoskeleton intervention. One study showed this improvement only in the subgroup that was recently injured and not in the chronically injured group.3 Another study of 3 subjects that completed 20 sessions of Ekso training improved their velocity from 0.17±0.04m/s to 0.23±0.04m/s, which was a statistically significant change.4 Another reported that average gait speed increased by 2.1 times between sessions 1 and 12.5

Some studies, especially those using non-ambulatory subjects, completed gait speed assessments while subjects were wearing an exoskeleton. One such study was a crossover design that randomized 10 participants with chronic motor complete SCI to receive 10 sessions each of gait training with ABLE and with knee-ankle-foot orthoses (KAFOs). There was no significant difference between using ABLE and KAFOs in terms of gait speed.6 A case study comparing walking with KAFOs and Indego demonstrated the opposite: that walking was significantly faster in the Indego, around 0.17 m/s as compared to 0.1 m/s in KAFOs.7 Another study was a crossover trial that assigned people to 12 weeks of Ekso or ReWalk walking and 12 weeks of usual activity, randomized for which they received first. Most participants improved gait speed, with 34% exceeding 0.4 m/s.8

Studies also reported different speeds that the subjects were able to walk in an exoskeleton. Community gait speed was defined as 0.49 m/s.9 Most of these studies utilized participants with complete SCI. Studies reported a range of gait speeds in exoskeletons, with most reporting speeds between 0.1-0.4 m/s. 10–19 Other studies included speed ranges that were faster than 0.4 m/s20–22 or slower than 0.1 m/s.23 The fastest speed noted in the literature was 0.71 m/s and was tested in the ReWalk.22 One review reported the average speed among all exoskeletons at 0.31 m/s24, while another reported a slightly slower 0.26 m/s.25 One study broke down speed in the Indego by level of injury, with those with motor complete tetraplegia walking at a speed of 0.22 m/s, those with upper thoracic motor complete injuries walking at 0.26 m/s, and those with lower thoracic motor complete injuries walking at 0.45 m/s.26 Level of injury was also shown to impact speed of walking in ReWalk, with lower injuries walking at a faster speed of 0.21 m/s and those with higher level injuries walking at 0.12 m/s.27

Some studies examined how walking speed in an exoskeleton changed as participants became more proficient and independent at using the device. One study showed a 52% increase in speed while walking in the exoskeleton, though this was over 100 hours of training28, while a similar dosage in another study only showed a 30% increase in speed.29 When comparing an early Ekso walking session (session #4) to a later one (session #20), an increase in walking speed was found, however, it was not statistically significant.30 This is directly contrary to another study that showed participants walking 3.2 times faster during their 25th training session versus session 2, reaching speeds averaging 0.4 m/s by the end of the study.31

Other studies examined gait speed in or resulting from use of an exoskeleton in combination with another treatment method including epidural stimulation.32 Another study looked at Ekso use in sequence with lower limb Functional Electrical Stimulation (FES), receiving 20 sessions of each in randomized order. In the group that received exoskeleton walking first, 10MWT improved by 30% after exoskeleton training, but no further improvement was noted with the subsequent FES sessions.33

There are multiple review articles focusing on people with SCI. Most have mixed results on how exoskeleton usage affects gait speed. Some report thatthere is no difference between training in an exoskeleton and a control treatment34,35 while others report speed improvements resulting from using an exoskeleton.36–39 Others reported improvements either only or more significantly in specific subgroups of persons with SCI, such as those with acute injuries.35,39 One review compared a wearable exoskeleton to the Lokomat and determined that the probability of the wearable device ranking first in improving gait speed was 89%.40 Another review examined factors that might influence gait speed in non-ambulatory individuals using an exoskeleton. These included age, injury duration, injury level, and number of training sessions, and found that more sessions, greater age, and lower level of injury correlated with faster gait speed.25

*Stroke (CVA)*

The research in subjects with CVA measures changes in gait speed as a result of an exoskeleton intervention, with outcomes measured without the exoskeleton. This body of research begins strongly with six randomized controlled trials, all of which utilize Ekso. With equal training time, 40 subjects were allocated with a 1:1 ratio to receive treatment 5 days a week for 8 weeks. Those who received Ekso training met the Minimal Detectable Change (MDC) for 10MWT whereas those who received only conventional treatment did not.41 Thirty participants with chronic CVA were assigned to receive Ekso or physical therapist aided gait training 3 times a week for 8 weeks. The group receiving Ekso gait training improved median gait speed by 0.4 m/s whereas the conventional treatment group only improved by a median of 0.1 m/s.42 Participants with subacute stroke were randomized to receive conventional (n=9) or ExoAtlet (n=16) training three times per week for 4 weeks in addition to 5 times a week traditional therapy. Median gait speed improved in the ExoAtlet group by 0.28 m/s whereas it did not improve in the conventional therapy only group.43 Another article randomized 40 persons with chronic stroke with a 1:1 allocation to receive Ekso or conventional training on all weekdays for 8 weeks and demonstrated superiority of the Ekso for increasing gait speed measured by the 10MWT.44 All subjects in the Ekso group surpassed the MCID whereas only 40% of those in the conventional training group met this metric.44 However, a similar study of 75 subjects with subacute CVA who received 5 sessions per week for 3 weeks of either Ekso or conventional gait training showed improvements in both groups that were not significantly different.45 These studies were all completed in a research setting, where dosage was higher than what can be expected in an insurance-based healthcare system. The final known randomized controlled trial was completed in the rehab setting, where patients with subacute CVA of less than 3 months who were unable to walk (Functional ambulation capacity of 0-1) were randomized to receive standard physical therapy or Ekso training until discharge, where this method was to replace 75% of physical therapy time, which roughly amounted to 3 sessions per week for 60 minutes per session. Some of the participants in the Ekso group declined further intervention and therefore results were analyzed as-treated, with the Ekso group (n=14) reigning superior to the usual care group (n=22) in terms of improving gait speed between discharge and 6-month follow-up.46

Another study completed in the setting of inpatient rehabilitation examined 14 subjects with moderate to severe CVA who received both standard of care and Ekso training and found that 12 participants showed improvement with gait speed measured by the 10MWT. 47 There was a moderate correlation between number of robotic sessions and change in speed.47

While not conducted in a rehabilitation setting, there are a few other studies that employed a smaller dosage of robotic training. One of these used Indego in a clinical setting for four sessions over two weeks in 8 patients with acute stroke and 30 with chronic stroke. Walking speed for the chronic group significantly increased from 0.16±0.54 m/s to 0.26±1.59 m/s.48 A similar increase was seen in the acute group, improving from 0.13±1.09 m/s to 0.24±1.16 m/s.48 Another study looked at changes resulting from a single session of walking in Ekso using a motion capture system and showed that 6 participants with chronic CVA improved speed by 0.01 m/s, which is a small, insignificant change.49

The remainder of the research using subjects post stroke is completed in a research setting, mostly with a pre-post design. Some studies showed positive improvements when comparing baseline to post-intervention. One such study utilized 46 patients with strokes that occurred 2 weeks to 6 months before and assigned them to use Ekso for an average of 15±2 sessions over 3 to 5 weeks. Thirty-two participants were ambulant at the study start and these participants improved their gait speed measured by 10MWT significantly from 0.31±0.22 m/s to 0.46±0.25 m/s.50 A study with slightly shorter dosage of 12 Ekso sessions offered 3 times per week for persons with subacute (n=12) and chronic (n=11) stroke showed significant change in walking velocity from baseline to conclusion of all Ekso sessions in both the subacute and chronic subgroups.51 A small study of 2 patients with acute CVA who walked for 30 minutes, three times a week for 10 weeks in Ekso showed improvement of walking speed by 0.74 and 1.0 m/s.52

Other studies, however, showed no significant changes between baseline and post-intervention. A study that showed no significant change tested 8 subjects who were able to walk without assistance prior to 15 sessions of Ekso training over 3 weeks. The average change in gait speed was 0.22±0.34 m/s with a p value of 0.11, which is approaching significance.53 Another study showing no change in gait speed had subjects complete 12.6±1.95 sessions of Ekso walking over 25.6±12.1 days.54

One study looked at exoskeletons as part of a high intensity technology assisted training program for persons post CVA. Fourteen patients exercised for 12-21 days, receiving between 28-82 technology-assisted sessions and improved their average gait speed from 0.40 to 0.47 m/s.55

There are also a number of review articles that comment on gait speed in persons with stroke. Some reviews showed that exoskeletons improve gait speed at end of intervention56–58, while others did not show significant differences at end of intervention59,60 or at follow up.56,57,59 Other reviews reported on mixed results of the individual studies included and did not determine a firm conclusion as to whether gait speed is significantly affected by use of an exoskeleton.61 When different treatment methods were compared, one review concluded that the best at improving gait speed was conventional therapy plus body weight support training plus robotic gait training62 while another article stated that it was a combination of robotic assisted training and virtual reality.63 Another review noted that over ground exoskeletons resulted in a faster gait velocity, whereas treadmill-based devices resulted in no difference in relation to controls.58

*Multiple Sclerosis (MS)*

Only a few articles exist on how exoskeletons can impact speed in persons with MS. Two of these are randomized controlled trials. The first is a small study of four subjects with relapsing-remitting MS who were randomized to either complete eight sessions of gait training using Ekso or conventional therapy. When tested with the Timed 25 Foot Walk (T25FW), the Ekso group (n=18) improved by 15% while the control group improved only by 8%.64 The other study had all 36 participants complete weekly 1-hour physical therapy sessions over 3 months, with the Ekso group receiving an additional 2 sessions per week of exoskeleton training. Results showed that the control group increased the time it took to complete the 10MWT by an average of 1.22 seconds, which was statistically significant, while the Ekso group increased by an average of 0.59 seconds, which was not statistically significant.65 This suggests that exoskeleton walking could preserve gait function as opposed to the typical decline we expect to see with MS.

Other studies, while not all controlled, also agreed that treatment with an exoskeleton either increased gait speed in persons with MS or prevented the slowing of gait speed typical in this diagnosis. A retrospective study examined 20 patients who either received treatment with Ekso or traditional gait training. These participants were matched for age, sex, duration of disease, and Expanded Disability Status Scale (EDSS). Only in the group receiving Ekso did the gait speed measured by 10MWT significantly improve by 0.85 seconds versus a 0.68 second decline in the control group.66 Fourteen individuals with EDSS from 5 to 6.5 (disability affects full daily activities, can walk 20-200m without resting, may use walking aid) completed 15 sessions of Ekso over three weeks and showed significant increase in gait speed from baseline, 0.7 m/s, to completion of Ekso sessions, 0.87 m/s, measured by T25FW.67 Another study used 10 subjects with more severe disability, EDSS between 6-7.5, which means that at minimum, they require a walking aid or they utilize a wheelchair but can self-propel. They walked for 15 sessions in the Ekso over three weeks and during this time, gait speed measured with the T25FW improved from 0.35±0.18 m/s to 0.42±0.23 m/s, which was statistically significant.68 Interestingly, another study with a longer intervention of 3 times walking in ReWalk per week for 8 weeks, only had 5 of 13 participants complete the protocol and none improved on speed.69

One review focused on subjects with MS and reported that robotic treatment had a positive effect on gait speed, though these findings were not significantly different than those reported from conventional therapy.70 Another review showed significant improvement after robotic intervention with regard to walking velocity.61

*Acquired Brain Injury*

Only three articles exist that specifically focus on subjects with ABI and two primarily focus on spatiotemporal characteristics of gait but did measure speed via a Zeno walkway. In one study comparing two individuals with ABI and one reference healthy control, walking with Ekso for 2-3 days per week for four weeks as an outpatient resulted in increased walking speed for the ABI group outside of the exoskeleton, though it was still slower than the healthy control.71 The other article used a similar frequency of treatment at three times per week of Ekso walking over four weeks. Seven subjects completed the protocol, and five of those improved their gait speed from baseline to completion of the intervention.72 A case study participant who underwent four weeks of Ekso training improved his gait speed from 0.68 m/s to 0.74 m/s.73

*Review Articles*

One review article examined older adults with a variety of diagnoses that utilized different exoskeletons. Maximum walking speed and self-selected gait speed increased after exoskeleton training.74

*Conclusion*

While there are many articles that assess gait speed either in or resulting from an exoskeleton, results are not consistent. Most articles report an improvement in gait speed from using an exoskeleton, and none noted a worsening of gait speed, with the exception of articles examining persons with MS who worsened less so than controls. Inconclusive results may have been due to different exoskeleton devices being used and varying dosage of intervention.

**References**

1. Edwards DJ, Forrest G, Cortes M, et al. Walking improvement in chronic incomplete spinal cord injury with exoskeleton robotic training (WISE): a randomized controlled trial. *Spinal Cord*. 2022;60(6):522-532. doi:10.1038/s41393-022-00751-8

2. Chang SH, Afzal T, TIRR SCI Clinical Exoskeleton Group, Berliner J, Francisco GE. Exoskeleton-assisted gait training to improve gait in individuals with spinal cord injury: a pilot randomized study. *Pilot Feasibility Stud*. 2018;4:62. doi:10.1186/s40814-018-0247-y

3. Bach Baunsgaard C, Vig Nissen U, Katrin Brust A, et al. Gait training after spinal cord injury: safety, feasibility and gait function following 8 weeks of training with the exoskeletons from Ekso Bionics. *Spinal Cord*. 2018;56(2):106-116. doi:10.1038/s41393-017-0013-7

4. Sale P, Russo EF, Russo M, et al. Effects on mobility training and de-adaptations in subjects with Spinal Cord Injury due to a Wearable Robot: a preliminary report. *BMC Neurol*. 2016;16(1):12. doi:10.1186/s12883-016-0536-0

5. Wright MA, Herzog F, Mas-Vinyals A, et al. Multicentric investigation on the safety, feasibility and usability of the ABLE lower-limb robotic exoskeleton for individuals with spinal cord injury: a framework towards the standardisation of clinical evaluations. *J Neuroeng Rehabil*. 2023;20(1):45. doi:10.1186/s12984-023-01165-0

6. Rodríguez-Fernández A, Lobo-Prat J, Tarragó R, et al. Comparing walking with knee-ankle-foot orthoses and a knee-powered exoskeleton after spinal cord injury: a randomized, crossover clinical trial. *Sci Rep*. 2022;12(1):19150. doi:10.1038/s41598-022-23556-4

7. Farris RJ, Quintero HA, Murray SA, Ha KH, Hartigan C, Goldfarb M. A Preliminary Assessment of Legged Mobility Provided by a Lower Limb Exoskeleton for Persons With Paraplegia. *IEEE Trans Neural Syst Rehabil Eng*. 2014;22(3):482-490. doi:10.1109/TNSRE.2013.2268320

8. Hong E, Gorman PH, Forrest GF, et al. Mobility Skills With Exoskeletal-Assisted Walking in Persons With SCI: Results From a Three Center Randomized Clinical Trial. *Front Robot AI*. 2020;7:93. doi:10.3389/frobt.2020.00093

9. Andrews AW, Chinworth SA, Bourassa M, Garvin M, Benton D, Tanner S. Update on distance and velocity requirements for community ambulation. *J Geriatr Phys Ther*. 2010;33(3):128-134.

10. Kozlowski AJ, Bryce TN, Dijkers MP. Time and Effort Required by Persons with Spinal Cord Injury to Learn to Use a Powered Exoskeleton for Assisted Walking. *Top Spinal Cord Inj Rehabil*. 2015;21(2):110-121. doi:10.1310/sci2102-110

11. Alamro RA, Chisholm AE, Williams AMM, Carpenter MG, Lam T. Overground walking with a robotic exoskeleton elicits trunk muscle activity in people with high-thoracic motor-complete spinal cord injury. *J Neuroeng Rehabil*. 2018;15(1):109. doi:10.1186/s12984-018-0453-0

12. Kressler J, Thomas CK, Field-Fote EC, et al. Understanding Therapeutic Benefits of Overground Bionic Ambulation: Exploratory Case Series in Persons With Chronic, Complete Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation*. 2014;95(10):1878-1887.e4. doi:10.1016/j.apmr.2014.04.026

13. Ramanujam A, Cirnigliaro CM, Garbarini E, Asselin P, Pilkar R, Forrest GF. Neuromechanical adaptations during a robotic powered exoskeleton assisted walking session. *J Spinal Cord Med*. 2018;41(5):518-528. doi:10.1080/10790268.2017.1314900

14. Koljonen PA, Virk AS, Jeong Y, et al. Outcomes of a Multicenter Safety and Efficacy Study of the SuitX Phoenix Powered Exoskeleton for Ambulation by Patients With Spinal Cord Injury. *Front Neurol*. 2021;12:689751. doi:10.3389/fneur.2021.689751

15. Benson I, Hart K, Tussler D, Van Middendorp JJ. Lower-limb exoskeletons for individuals with chronic spinal cord injury: findings from a feasibility study. *Clin Rehabil*. 2016;30(1):73-84. doi:10.1177/0269215515575166

16. Guanziroli E, Cazzaniga M, Colombo L, Basilico S, Legnani G, Molteni F. Assistive powered exoskeleton for complete spinal cord injury: correlations between walking ability and exoskeleton control. *Eur J Phys Rehabil Med*. 2019;55(2):209-216. doi:10.23736/S1973-9087.18.05308-X

17. Tefertiller C, Hays K, Jones J, et al. Initial Outcomes from a Multicenter Study Utilizing the Indego Powered Exoskeleton in Spinal Cord Injury. *Top Spinal Cord Inj Rehabil*. 2018;24(1):78-85. doi:10.1310/sci17-00014

18. Farris RJ, Quintero HA, Goldfarb M. Preliminary Evaluation of a Powered Lower Limb Orthosis to Aid Walking in Paraplegic Individuals. *IEEE Trans Neural Syst Rehabil Eng*. 2011;19(6):652-659. doi:10.1109/TNSRE.2011.2163083

19. Evans N, Hartigan C, Kandilakis C, Pharo E, Clesson I. Acute Cardiorespiratory and Metabolic Responses During Exoskeleton-Assisted Walking Overground Among Persons with Chronic Spinal Cord Injury. *Topics in Spinal Cord Injury Rehabilitation*. 2015;21(2):122-132. doi:10.1310/sci2102-122

20. Khan AS, Livingstone DC, Hurd CL, 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 NeuroEngineering Rehabil*. 2019;16(1):145. doi:10.1186/s12984-019-0585-x

21. Esquenazi A, Talaty M, Packel A, Saulino M. The ReWalk Powered Exoskeleton to Restore Ambulatory Function to Individuals with Thoracic-Level Motor-Complete Spinal Cord Injury. *American Journal of Physical Medicine & Rehabilitation*. 2012;91(11):911-921. doi:10.1097/PHM.0b013e318269d9a3

22. Yang A, Asselin P, Knezevic S, Kornfeld S, Spungen AM. Assessment of In-Hospital Walking Velocity and Level of Assistance in a Powered Exoskeleton in Persons with Spinal Cord Injury. *Top Spinal Cord Inj Rehabil*. 2015;21(2):100-109. doi:10.1310/sci2102-100

23. Kerdraon J, Previnaire JG, Tucker M, et al. Evaluation of safety and performance of the self balancing walking system Atalante in patients with complete motor spinal cord injury. *Spinal Cord Ser Cases*. 2021;7(1):71. doi:10.1038/s41394-021-00432-3

24. Tan K, Koyama S, Sakurai H, Teranishi T, Kanada Y, Tanabe S. Wearable robotic exoskeleton for gait reconstruction in patients with spinal cord injury: A literature review. *Journal of Orthopaedic Translation*. 2021;28:55-64. doi:10.1016/j.jot.2021.01.001

25. Louie DR, Eng JJ, Lam T, Spinal Cord Injury Research Evidence (SCIRE) Research Team. Gait speed using powered robotic exoskeletons after spinal cord injury: a systematic review and correlational study. *J Neuroeng Rehabil*. 2015;12:82. doi:10.1186/s12984-015-0074-9

26. Hartigan C, Kandilakis C, Dalley S, et al. Mobility Outcomes Following Five Training Sessions with a Powered Exoskeleton. *Top Spinal Cord Inj Rehabil*. 2015;21(2):93-99. doi:10.1310/sci2102-93

27. Zeilig G, Weingarden H, Zwecker M, Dudkiewicz I, Bloch A, Esquenazi A. Safety and tolerance of the ReWalkTM exoskeleton suit for ambulation by people with complete spinal cord injury: a pilot study. *J Spinal Cord Med*. 2012;35(2):96-101. doi:10.1179/2045772312Y.0000000003

28. Husain SR, Ramanujam A, Momeni K, Forrest GF. Effects of Exoskeleton Training Intervention on Net Loading Force in Chronic Spinal Cord Injury. In: *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE; 2018:2793-2796. doi:10.1109/EMBC.2018.8512768

29. Ramanujam A, Momeni K, Husain SR, et al. Mechanisms for improving walking speed after longitudinal powered robotic exoskeleton training for individuals with spinal cord injury. In: *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE; 2018:2805-2808. doi:10.1109/EMBC.2018.8512821

30. Mazzoleni S, Battini E, Rustici A, Stampacchia G. An integrated gait rehabilitation training based on Functional Electrical Stimulation cycling and overground robotic exoskeleton in complete spinal cord injury patients: Preliminary results. In: *2017 International Conference on Rehabilitation Robotics (ICORR)*. IEEE; 2017:289-293. doi:10.1109/ICORR.2017.8009261

31. McIntosh K, Charbonneau R, Bensaada Y, Bhatiya U, Ho C. The Safety and Feasibility of Exoskeletal-Assisted Walking in Acute Rehabilitation After Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation*. 2020;101(1):113-120. doi:10.1016/j.apmr.2019.09.005

32. Gorgey AS, Gill S, Holman ME, et al. The feasibility of using exoskeletal‐assisted walking with epidural stimulation: a case report study. *Ann Clin Transl Neurol*. 2020;7(2):259-265. doi:10.1002/acn3.50983

33. Stampacchia G, Olivieri M, Rustici A, D’Avino C, Gerini A, Mazzoleni S. Gait rehabilitation in persons with spinal cord injury using innovative technologies: an observational study. *Spinal Cord*. 2020;58(9):988-997. doi:10.1038/s41393-020-0454-2

34. Li R, Ding M, Wang J, et al. Effectiveness of robotic-assisted gait training on cardiopulmonary fitness and exercise capacity for incomplete spinal cord injury: A systematic review and meta-analysis of randomized controlled trials. *Clin Rehabil*. 2023;37(3):312-329. doi:10.1177/02692155221133474

35. Liu W, Chen J. The efficacy of exoskeleton robotic training on ambulation recovery in patients with spinal cord injury: A meta-analysis. *The Journal of Spinal Cord Medicine*. Published online August 3, 2023:1-10. doi:10.1080/10790268.2023.2214482

36. Mekki M, Delgado AD, Fry A, Putrino D, Huang V. Robotic Rehabilitation and Spinal Cord Injury: a Narrative Review. *Neurotherapeutics*. 2018;15(3):604-617. doi:10.1007/s13311-018-0642-3

37. Stampacchia G, Gazzotti V, Olivieri M, et al. Gait robot-assisted rehabilitation in persons with spinal cord injury: A scoping review. Morone G, Riener R, Mazzoleni S, eds. *NRE*. 2022;51(4):609-647. doi:10.3233/NRE-220061

38. Rodriguez Tapia G, Doumas I, Lejeune T, Previnaire JG. Wearable powered exoskeletons for gait training in tetraplegia: a systematic review on feasibility, safety and potential health benefits. *Acta Neurol Belg*. 2022;122(5):1149-1162. doi:10.1007/s13760-022-02011-1

39. Patathong T, Klaewkasikum K, Woratanarat P, et al. The efficacy of gait rehabilitations for the treatment of incomplete spinal cord injury: a systematic review and network meta-analysis. *J Orthop Surg Res*. 2023;18(1):60. doi:10.1186/s13018-022-03459-w

40. Zhang L, Lin F, Sun L, Chen C. Comparison of Efficacy of Lokomat and Wearable Exoskeleton-Assisted Gait Training in People With Spinal Cord Injury: A Systematic Review and Network Meta-Analysis. *Front Neurol*. 2022;13:772660. doi:10.3389/fneur.2022.772660

41. Calabrò RS, Naro A, Russo M, et al. Shaping neuroplasticity by using powered exoskeletons in patients with stroke: a randomized clinical trial. *J NeuroEngineering Rehabil*. 2018;15(1):35. doi:10.1186/s12984-018-0377-8

42. De Luca R, Maresca G, Balletta T, et al. Does overground robotic gait training improve non-motor outcomes in patients with chronic stroke? Findings from a pilot study. *Journal of Clinical Neuroscience*. 2020;81:240-245. doi:10.1016/j.jocn.2020.09.070

43. Yoo HJ, Bae CR, Jeong H, Ko MH, Kang YK, Pyun SB. Clinical efficacy of overground powered exoskeleton for gait training in patients with subacute stroke: A randomized controlled pilot trial. *Medicine*. 2023;102(4):e32761. doi:10.1097/MD.0000000000032761

44. Naro A, Pignolo L, Calabrò RS. Brain Network Organization Following Post-Stroke Neurorehabilitation. *Int J Neur Syst*. 2022;32(04):2250009. doi:10.1142/S0129065722500095

45. Molteni F, Guanziroli E, Goffredo M, et al. Gait Recovery with an Overground Powered Exoskeleton: A Randomized Controlled Trial on Subacute Stroke Subjects. *Brain Sciences*. 2021;11(1):104. doi:10.3390/brainsci11010104

46. Louie DR, Mortenson WB, Durocher M, et al. Efficacy of an exoskeleton-based physical therapy program for non-ambulatory patients during subacute stroke rehabilitation: a randomized controlled trial. *J NeuroEngineering Rehabil*. 2021;18(1):149. doi:10.1186/s12984-021-00942-z

47. Karunakaran KK, Gute S, Ames GR, Chervin K, Dandola CM, Nolan KJ. Effect of robotic exoskeleton gait training during acute stroke on functional ambulation. *NeuroRehabilitation*. 2021;48(4):493-503. doi:10.3233/NRE-210010

48. Nolan KJ, Karunakaran KK, Roberts P, et al. Utilization of Robotic Exoskeleton for Overground Walking in Acute and Chronic Stroke. *Front Neurorobot*. 2021;15:689363. doi:10.3389/fnbot.2021.689363

49. Swank C, Almutairi S, Wang-Price S, Gao F. Immediate kinematic and muscle activity changes after a single robotic exoskeleton walking session post-stroke. *Topics in Stroke Rehabilitation*. 2020;27(7):503-515. doi:10.1080/10749357.2020.1728954

50. Goffredo M, Guanziroli E, Pournajaf S, et al. Overground wearable powered exoskeleton for gait training in subacute stroke subjects: clinical and gait assessments. *Eur J Phys Rehabil Med*. 2020;55(6). doi:10.23736/S1973-9087.19.05574-6

51. Molteni F, Gasperini G, Gaffuri M, et al. Wearable robotic exoskeleton for overground gait training in sub-acute and chronic hemiparetic stroke patients: preliminary results. *Eur J Phys Rehabil Med*. 2017;53(5). doi:10.23736/S1973-9087.17.04591-9

52. Nolan KJ, Ames GR, Dandola CM, et al. Intensity Modulated Exoskeleton Gait Training Post Stroke. In: *2023 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. IEEE; 2023:1-4. doi:10.1109/EMBC40787.2023.10340452

53. Infarinato F, Romano P, Goffredo M, et al. Functional Gait Recovery after a Combination of Conventional Therapy and Overground Robot-Assisted Gait Training Is Not Associated with Significant Changes in Muscle Activation Pattern: An EMG Preliminary Study on Subjects Subacute Post Stroke. *Brain Sciences*. 2021;11(4):448. doi:10.3390/brainsci11040448

54. Zhu F, Kern M, Fowkes E, et al. Effects of an exoskeleton-assisted gait training on post-stroke lower-limb muscle coordination. *J Neural Eng*. 2021;18(4). doi:10.1088/1741-2552/abf0d5

55. Schuster-Amft C, Kool J, Möller JC, et al. Feasibility and cost description of highly intensive rehabilitation involving new technologies in patients with post-acute stroke—a trial of the Swiss RehabTech Initiative. *Pilot Feasibility Stud*. 2022;8(1):139. doi:10.1186/s40814-022-01086-0

56. Hsu TH, Tsai CL, Chi JY, Hsu CY, Lin YN. Effect of wearable exoskeleton on post-stroke gait: A systematic review and meta-analysis. *Annals of Physical and Rehabilitation Medicine*. 2023;66(1):101674. doi:10.1016/j.rehab.2022.101674

57. Leow XRG, Ng SLA, Lau Y. Overground Robotic Exoskeleton Training for Patients With Stroke on Walking-Related Outcomes: A Systematic Review and Meta-analysis of Randomized Controlled Trials. *Archives of Physical Medicine and Rehabilitation*. 2023;104(10):1698-1710. doi:10.1016/j.apmr.2023.03.006

58. Yang J, Zhu Y, Li H, Wang K, Li D, Qi Q. Effect of robotic exoskeleton training on lower limb function, activity and participation in stroke patients: a systematic review and meta-analysis of randomized controlled trials. *Front Neurol*. 2024;15:1453781. doi:10.3389/fneur.2024.1453781

59. Mehrholz J, Thomas S, Werner C, Kugler J, Pohl M, Elsner B. Electromechanical-Assisted Training for Walking After Stroke: A Major Update of the Evidence. *Stroke*. 2017;48(8). doi:10.1161/STROKEAHA.117.018018

60. Nedergård H, Arumugam A, Sandlund M, Bråndal A, Häger CK. Effect of robotic-assisted gait training on objective biomechanical measures of gait in persons post-stroke: a systematic review and meta-analysis. *J Neuroeng Rehabil*. 2021;18(1):64. doi:10.1186/s12984-021-00857-9

61. Yang J, Gong Y, Yu L, Peng L, Cui Y, Huang H. Effect of exoskeleton robot-assisted training on gait function in chronic stroke survivors: a systematic review of randomised controlled trials. *BMJ Open*. 2023;13(9):e074481. doi:10.1136/bmjopen-2023-074481

62. Moucheboeuf G, Griffier R, Gasq D, et al. Effects of robotic gait training after stroke: A meta-analysis. *Ann Phys Rehabil Med*. 2020;63(6):518-534. doi:10.1016/j.rehab.2020.02.008

63. Zhang B, Wong KP, Kang R, Fu S, Qin J, Xiao Q. Efficacy of Robot-Assisted and Virtual Reality Interventions on Balance, Gait, and Daily Function in Patients With Stroke: A Systematic Review and Network Meta-analysis. *Archives of Physical Medicine and Rehabilitation*. 2023;104(10):1711-1719. doi:10.1016/j.apmr.2023.04.005

64. Androwis GJ, Kwasnica MA, Niewrzol P, et al. Mobility and Cognitive Improvements Resulted from Overground Robotic Exoskeleton Gait-Training in Persons with MS. In: *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE; 2019:4454-4457. doi:10.1109/EMBC.2019.8857029

65. Berriozabalgoitia R, Bidaurrazaga-Letona I, Otxoa E, Urquiza M, Irazusta J, Rodriguez-Larrad A. Overground Robotic Program Preserves Gait in Individuals With Multiple Sclerosis and Moderate to Severe Impairments: A Randomized Controlled Trial. *Archives of Physical Medicine and Rehabilitation*. 2021;102(5):932-939. doi:10.1016/j.apmr.2020.12.002

66. Russo M, Maggio MG, Naro A, et al. Can powered exoskeletons improve gait and balance in multiple sclerosis? A retrospective study. *International Journal of Rehabilitation Research*. 2021;44(2):126-130. doi:10.1097/MRR.0000000000000459

67. Drużbicki M, Guzik A, Przysada G, et al. Effects of Robotic Exoskeleton-Aided Gait Training in the Strength, Body Balance, and Walking Speed in Individuals With Multiple Sclerosis: A Single-Group Preliminary Study. *Arch Phys Med Rehabil*. 2021;102(2):175-184. doi:10.1016/j.apmr.2020.10.122

68. Afzal T, Tseng SC, Lincoln JA, Kern M, Francisco GE, Chang SH. Exoskeleton-assisted Gait Training in Persons With Multiple Sclerosis: A Single-Group Pilot Study. *Arch Phys Med Rehabil*. 2020;101(4):599-606. doi:10.1016/j.apmr.2019.10.192

69. Kozlowski AJ, Fabian M, Lad D, Delgado AD. Feasibility and Safety of a Powered Exoskeleton for Assisted Walking for Persons With Multiple Sclerosis: A Single-Group Preliminary Study. *Archives of Physical Medicine and Rehabilitation*. 2017;98(7):1300-1307. doi:10.1016/j.apmr.2017.02.010

70. Calabrò RS, Cassio A, Mazzoli D, et al. What does evidence tell us about the use of gait robotic devices in patients with multiple sclerosis? A comprehensive systematic review on functional outcomes and clinical recommendations. *Eur J Phys Rehabil Med*. 2021;57(5):841-849. doi:10.23736/S1973-9087.21.06915-X

71. Karunakaran KK, Pamula S, Nolan KJ. Changes in Center of Pressure after Robotic Exoskeleton Gait Training in Adults with Acquired Brain Injury. *Annu Int Conf IEEE Eng Med Biol Soc*. 2021;2021:4666-4669. doi:10.1109/EMBC46164.2021.9629921

72. Karunakaran KK, Ehrenberg N, Cheng J, Bentley K, Nolan KJ. Kinetic Gait Changes after Robotic Exoskeleton Training in Adolescents and Young Adults with Acquired Brain Injury. *Appl Bionics Biomech*. 2020;2020:8845772. doi:10.1155/2020/8845772

73. Karunakaran KK, Nisenson DM, Nolan KJ. Alterations in Cortical Activity due to Robotic Gait Training in Traumatic Brain Injury. *Annu Int Conf IEEE Eng Med Biol Soc*. 2020;2020:3224-3227. doi:10.1109/EMBC44109.2020.9175764

74. Gavrila Laic RA, Firouzi M, Claeys R, Bautmans I, Swinnen E, Beckwée D. A State-of-the-Art of Exoskeletons in Line with the WHO’s Vision on Healthy Aging: From Rehabilitation of Intrinsic Capacities to Augmentation of Functional Abilities. *Sensors (Basel)*. 2024;24(7):2230. doi:10.3390/s24072230

| **Title** | **Authors** | **Journal** | **Device** | **Diagnosis** |
| --- | --- | --- | --- | --- |
| Effect of robotic exoskeleton training on lower limb function, activity and participation in stroke patients: a systematic review and meta-analysis of randomized controlled trials | Yang J, Zhu Y, Li H, Wang K, Li D, Qi Q | Front Neurol. 2024 Aug 13:15:1453781 | Multiple – Review Article | CVA |
| Exoskeleton-based exercises for overground gait and balance rehabilitation in spinal cord injury: a systematic review of dose and dosage parameters | Nepomuceno P, Souza WH, Pakosh M, Musselman KE, Craven BC | J Neuroeng Rehabil. 2024 May 5;21(1):73 | Multiple – Review Article | SCI |
| A State-of-the-Art of Exoskeletons in Line with the WHO’s Vision on Healthy Aging: From Rehabilitation of Intrinsic Capacities to Augmentation of Functional Abilities. | Gavrila Laic RA, Firouzi M, Claeys R, Bautmans I, Swinnen E, Beckwée D. | Sensors (Basel). 2024 Mar 30;24(7):2230 | Multiple – Review Article | Multiple – Review Article |
| Overground robotic exoskeleton training for patients with stroke on walking-related outcomes: A systematic review and meta-analysis of randomised controlled trials | Leow XRG, Ng SLA, Lau Y | Arch Phys Med Rehabil. 2023 Oct;104(10):1698-1710. | Multiple – Review Article | CVA |
| Efficacy of robot-assisted and virtual reality interventions on balance, gait, and daily function in patients with stroke: A systematic review and network meta-analysis | Zhang B, Wong KP, Kang R, Fu S, Qin J, Xiao Q | Arch Phys Med Rehabil. 2023 Oct;104(10):1711-1719 | Multiple – Review Article | CVA |
| Effect of exoskeleton robot-assisted training on gait function in chronic stroke survivors: a systematic review of randomised controlled trials | Yang J, Gong Y,  Yu L, Peng L, Cui Y, Huang H | BMJ Open. 2023 Sep 14;13(9):e074481 | Multiple – Review Article | CVA |
| The efficacy of exoskeleton robotic training on ambulation recovery in patients with spinal cord injury: A meta-analysis | Liu W, Chen J | J Spinal Cord Med. 2023 Aug 3:1-10 | Multiple – Review Article | SCI |
| Intensity Modulated Exoskeleton Gait Training Post Stroke | Nolan KJ, Ames GR, Dandola CM, Breighner JE, Franco S, Karunakaran KK, Saleh S. | Annu Int Conf IEEE Eng Med Biol Soc. 2023 Jul:2023:1-4 | Ekso | CVA |
| 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 | Zhang C, Li N, Xue X, Lu X, Li D, Hong Q | Gait Posture. 2023 May:102:64-71 | Multiple – Review Article | SCI |
| Multicentric investigation on the safety, feasibility and usability of the ABLE lower-limb robotic exoskeleton for individuals with spinal cord injury: a framework towards the standardisation of clinical evaluations | Wright MA, Herzog F, Mas-Vinyals A, et al. | J Neuroeng Rehabil. 2023 Apr 12;20(1):45 | Able | SCI |
| Effect of Robot-Assisted Gait Training on Multiple Sclerosis: A Systematic Review and Meta-analysis of Randomized Controlled Trials. | Yang FA, Lin CL, Huang WC, Wang HY, Peng CW, Chen HC | Neurorehabil Neural Repair. 2023 Apr;37(4):228-239 | Multiple – Review Article | MS |
| Effectiveness of robotic-assisted gait training on cardiopulmonary fitness and exercise capacity for incomplete spinal cord injury: A systematic review and meta-analysis of randomized controlled trials | Li R, Ding M, Wang J, Pan H, Sun X, Huang L, Fu C, He C, Wei Q | Clin Rehabil. 2023 Mar;37(3):312-329 | Multiple – Review Article | SCI |
| Effect of wearable exoskeleton on post-stroke gait: A systematic review and meta-analysis | Hsu TH, Tsai CL, Chi JY, Hsu CY, Lin YN | Ann Phys Rehabil Med. 2023 Feb;66(1):101674 | Multiple – Review Article | CVA |
| Clinical efficacy of overground powered exoskeleton for gait training in patients with subacute stroke: A randomized controlled pilot trial | Yoo HJ, Bae CR, Jeong H, Ko MH, Kang YK, Pyun SB | Medicine (Baltimore). 2023 Jan 27;102(4):e32761 | ExoAtlet | CVA |
| The efficacy of gait rehabilitations for the treatment of incomplete spinal cord injury: a systematic review and network meta-analysis | Patathong T, Klaewkasikum K, Woratanarat P, Rattanasiri S, Anothaisintawee T, Woratanarat T, Thakkinstian A | J Orthop Surg Res. 2023 Jan 23;18(1):60 | Lokomat, Ekso | SCI |
| Effect of exoskeleton-assisted Body Weight-Supported Treadmill Training on gait function for patients with chronic stroke a scoping review | Yamamoto R, Sasaki S, Kuwahara W, Kawakami M, Kaneko F | J Neuroeng Rehabil. 2022 Dec 21;19(1):143 | Multiple – Review Article | CVA |
| Comparing walking with knee-ankle-foot orthoses and a knee-powered exoskeleton after spinal cord injury: a randomized, crossover clinical trial | Rodríguez-Fernández A, Lobo-Prat J, Tarragó R, Chaverri D, Iglesias X, Guirao-Cano L, Font-Llagunes JM | Sci Rep. 2022 Nov 9;12(1):19150 | Able | SCI |
| Wearable powered exoskeletons for gait training in tetraplegia: a systematic review on feasibility, safety and potential health benefits | Tapia GR, Doumas I, Lejeune T, Previnaire JG | Acta Neurol Belg. 2022 Oct;122(5):1149-1162 | Multiple – Review Article | SCI |
| Feasibility and cost description of highly intensive rehabilitation involving new technologies in patients with post-acute stroke | Schuster-Amft C, Kool J, Moller JC, Schweinfurther R, Ernst MJ, Reicherzer L, Ziller C, Schwab ME, Wieser S, Wirz M | Pilot Feasibility Stud. 2022 Jul 5;8(1):139 | Multiple | CVA |
| Walking improvement in chronic incomplete spinal cord injury with exoskeleton robotic training (WISE): a randomized controlled trial | Edwards DJ, Forrest G, Cortes M, Weightman MM, Sadowsky C, Chang SH, Furman K, Bialek A, Prokup S, Carlow J, VanHiel L, Kemp L, Musick D, Campo M, Jayaraman A | Spinal Cord. 2022 Jun;60(6):522-532 | Ekso | SCI |
| Brain Network Organization Following Post-Stroke Neurorehabilitation | Naro A, Pignolo L, Calabrò RS | Int J Neural Syst. 2022 Apr;32(4):2250009 | Ekso | CVA |
| Comparison of Efficacy of Lokomat and Wearable Exoskeleton-Assisted Gait Training in People With Spinal Cord Injury: A Systematic Review and Network Meta-Analysis. | Zhang L, Lin F, Sun L, Chen C. | Front Neurol. 2022 Apr 13:13:772660 | Multiple – Review Article | SCI |
| Gait robot-assisted rehabilitation in persons with spinal cord injury: A scoping review | Stampacchia G, Gazzotti V, Olivieri M, Andrenelli E, Bonaiuti D, Calabro RS, Carmignano SM, Cassio A, Fundaro C, Companini I, Mazzoli D, Cerulli S, Chisari C, Colombo V, Dalise S, Mazzoleni D, Melegari C, Merlo A, Boldrini P, Mazzoleni S, Posteraro F, Mazzucchelli M, Benanti P, Castelli E, Draicchio F, Falabella V, Galeri S, Gimigliano F, Grigioni M, Mazzon S, Molteni F, Morone G, Petrarca M, Picelli A, Senatore M, Turchetti G, Bizzarrini E | NeuroRehabilitation. 2022;51(4):609-647 | Multiple – Review Article | SCI |
| Changes in Center of Pressure after Robotic Exoskeleton Gait Training in Adults with Acquired Brain Injury | Karunakaran KK, Pamula S, Nolan KJ | Annu Int Conf IEEE Eng Med Biol Soc. 2021 Nov:2021:4666-4669 | Ekso | ABI |
| Efficacy of an exoskeleton-based physical therapy program for non-ambulatory patients during subacute stroke rehabilitation: a randomized controlled trial | Louie DR, Mortenson WB,  Durocher M,  Schneeberg A,  Teasell R,  Yao J,  Eng JJ | J Neuroeng Rehabil. 2021 Oct 10;18(1):149 | Ekso | CVA |
| What does evidence tell us about the use of gait robotic devices in patients with multiple sclerosis? A comprehensive systematic review on functional outcomes and clinical recommendations | Calabro RS, Cassio A, Mazzoli D, Andrenelli E, Bizzarini E, Capaninin I, Carmignano SM, Cerruli S, Chisari C, Colombo V, Dalise S, Fundaro C, Gazzotti V, Mazzoleni D, Mazzucchelli M, Melegari C, Merlo A, Stampacchia G, Boldrini P, Mazzoleni S, Posteraro F, Benati P, Castelli E, Draicchio F, Falabella V, Galeri S, Gimigliano F, Grigioni M, Mazzon S, Molteni F, Petrarca M, Picelli A, Senatore M, Turchetti G, Morone G, Bonaiuti D | Eur J Phys Rehabil Med. 2021 Oct;57(5):841-849 | Multiple – Review Article | MS |
| Utilization of Robotic Exoskeleton for Overground Walking in Acute and Chronic Stroke | Nolan KJ, Karunakaran KK, Roberts P, Tefertiller C, Walter AM, Zhang J, Leslie D, Jayaraman A and Francisco GE | Front Neurorobot. 2021 Sep 1:15:689363 | Indego | CVA |
| Evaluation of safety and performance of the self balancing walking system Atalante in patients with complete motor spinal cord injury | Kerdraon J, Previnaire JG, Tucker M, Coignard P, Allegre W, Kanppen E, Ames A | Spinal Cord Ser Cases. 2021 Aug 4;7(1):71 | Atalante | SCI |
| Outcomes of a Multicenter Safety and Efficacy Study of the SuitX Phoenix Powered Exoskeleton for Ambulation by Patients with Spinal Cord Injury | Koljonen PA, Virk AS, Jeong Y, McKinley M, Latorre J, Caballero A, Hu Y, Wong YW, Cheung K, Kazerooni H | Front Neurol. 2021 Jul 19:12:689751 | Phoenix | SCI |
| Effects of an exoskeleton-assisted gait training on post-stroke lower-limb muscle coordination | Zhu F, Kern M, Fowkes E, Afzal T, Contreras-Vidal JL, Francisco GE, Chang SH | J Neural Eng. 2021 Jun 4;18(4) | Ekso | CVA |
| Can powered exoskeletons improve gait and balance in multiple sclerosis? A retrospective study | M Russo, M Grazia Maggio, A Naro, S Portaro, B Porcari, T Balletta, R De Luca, L Raciti, RS Calabrò | Int J Rehabil Res. 2021 Jun 1;44(2):126-130 | Ekso | MS |
| Overground Robotic Program Preserves Gait in Individuals With Multiple Sclerosis and Moderate to Severe Impairments: A Randomized Controlled Trial | R Berriozabalgoitia, I Bidaurrazaga-Letona, Otxoa E, Urquiza M, Irazusta J, Rodriguez-Larrad A | Arch Phys Med Rehabil. 2021 May;102(5):932-939 | Ekso | MS |
| Functional Gait Recovery after a Combination of Conventional Therapy and Overground Robot-Assisted Gait Training Is Not Associated with Significant Changes in Muscle Activation Pattern: An EMG Preliminary Study on Subjects Subacute Post Stroke | Infarinato F, Romano P, Goffredo M, Ottaviani M, Galafate D, Gison A, Petruccelli S, Pournajaf S, Franceschini M | Brain Sci. 2021 Apr 1;11(4):448 | Ekso | CVA |
| Effect of robotic-assisted gait training on objective biomechanical measures of gait in persons post-stroke, a systematic review and meta-analysis | Nedergard H, Arumugam A, Sandlund M, Brandal A, Hager CK | J Neuroeng Rehabil. 2021 Apr 16;18(1):64 | Multiple – Review Article | CVA |
| Wearable robotic exoskeleton for gait reconstruction in patients with spinal cord injury: A literature review | Tan K, Koyama S, Sakurai H, Teranishi T, Kanada Y, Tanabe S | J Orthop Translat. 2021 Mar 1:28:55-64 | Multiple – Review Article | SCI |
| Effects of Robotic Exoskeleton aided gait training in the strength, body balance and walking speed in subjects with multiple sclerosis - a single-group, preliminary study | Drużbicki M, Guzik A, Przysada G, Perenc L, Brzozowska-Magoń A, Cygoń K, Boczula G, Bartosik-Psujek H | Arch Phys Med Rehabil. 2021 Feb;102(2):175-184 | Ekso | MS |
| Gait Recovery with an Overground Powered Exoskeleton: A Randomized Controlled Trial on Subacute Stroke Subjects | Molteni F, Guanziroli E, Goffredo M, Calabrò RS, Pournajaf S, Gaffuri M, Gasperini G, Filoni S, Baratta S, Galafate D, Le Pera D, Bramanti P, Franceschini M | Brain Sci. 2021 Jan 14;11(1):104. | Ekso | CVA |
| Effect of robotic exoskeleton gait training during acute stroke on functional ambulation | Karunakaran KK, Gute S, Ames GR, Chervin K,  Dandola CM, Nolan KJ | NeuroRehabilitation. 2021;48(4):493-503 | Ekso | CVA |
| Does overground robotic gait training improve non-motor outcomes in patients with chronic stroke? Findings from a pilot study | De Luca R, Maresca G, Balletta T, Cannavò A, Leonardi S, Latella D, Maggio MG, Portaro S, Naro A, Calabrò RS | J Clin Neurosci. 2020 Nov:81:240-245 | Ekso | CVA |
| Effects of robotic gait training after stroke: A meta-analysis | Moucheboeuf G, Griffier R, Gasq D, Glize B, Bouyer L, Dehail P, Cassoudesalle H | Ann Phys Rehabil Med. 2020 Nov;63(6):518-534 | Multiple – Review Article | CVA |
| Kinetic Gait Changes after Robotic Exoskeleton Training in Adolescents and Young Adults with Acquired Brain Injury | Karunakaran KK, Ehrenberg N, Cheng J, Bentley K, Nolan KJ | Appl Bionics Biomech. 2020 Oct 27:2020:8845772 | Ekso | ABI |
| Immediate kinematic and muscle activity changes after a single robotic exoskeleton walking session post-stroke. | Swank C, Almutairi S, Wang-Price S, Gao F. | Top Stroke Rehabil. 2020 Oct;27(7):503-515 | Ekso | CVA |
| Gait rehabilitation in persons with spinal cord injury using innovative technologies: an observational study | Stampacchia G, Olivieri M, Rustici A, D'Avino C, Gerini A, Mazzoleni S | Spinal Cord. 2020 Sep;58(9):988-997 | Ekso | SCI |
| Mobility Skills With Exoskeletal-Assisted Walking in Persons With SCI Results From a Three Center Randomized Clinical Trial | Hong EK, Gorman PH,Forrest GF, Asselin PK, Knezevic S, Scott W, Wojciehowski SB, Kornfeld S, Spungen AM | Front Robot AI. 2020 Aug 4:7:93 | ReWalk, Ekso | SCI |
| Alterations in Cortical Activity due to Robotic Gait Training in Traumatic Brain Injury | Karunakaran KK, Nisenson DM, Nolan KJ | Annu Int Conf IEEE Eng Med Biol Soc. 2020 Jul:2020:3224-3227 | Ekso | ABI |
| Exoskeleton-assisted Gait Training in Persons With Multiple Sclerosis: A Single-Group Pilot Study | Afzal T, Tseng SC, Lincoln JA, Kern M, Francisco GE, Chang SH | Arch Phys Med Rehabil. 2020 Apr;101(4):599-606 | Ekso | MS |
| The feasibility of using exoskeletal-assisted walking with epidural stimulation: a case report study | Gorgey AS, Gill S, Holman ME , Davis JC, Atri R, Bai O, Goetz L, Lester DL, Trainer R, Lavis TD | Ann Clin Transl Neurol. 2020 Feb;7(2):259-265 | Ekso | SCI |
| The safety and feasibility of exoskeletal assisted walking in acute rehabilitation following spinal cord injury. | McIntosh K, Charbonneau R, Bensaada Y, Bhatiya U, Ho C. | Arch Phys Med Rehabil. 2020 Jan;101(1):113-120 | Ekso | SCI |
| Overground wearable powered exoskeleton for gait training in subacute stroke subjects: clinical and gait assessments. | Goffredo M, Guanziroli E, Pournajaf S, Gaffuri M, Gasperini G, Filoni S, Baratta S, Damiani C, Franceschini M, Molteni F | Eur J Phys Rehabil Med. 2019 Dec;55(6):710-721 | Ekso | CVA |
| Retraining walking over ground in a powered exoskeleton after spinal cord injury: a prospective cohort study to examine functional gains and neuroplasticity | Khan AS, Livingstone DC, Hurd CL, Duchcherer J, Misiaszek JE, Gorassini MA, Manns PJ, Yang JF | J Neuroeng Rehabil. 2019 Nov 21;16(1):145 | ReWalk | SCI |
| Mobility and Cognitive Improvements Resulted from Overground Robotic Exoskeleton Gait-Training in Persons with MS. | Androwis GJ, Kwasnica MA, Niewrzol P, Popok P, Fakhoury FN, Sandroff BM, Yue GH, DeLuca J. | Annu Int Conf IEEE Eng Med Biol Soc. 2019 Jul:2019:4454-4457 | Ekso | MS |
| Cardiometabolic Challenges Provided by Variable Assisted Exoskeletal Versus Overground Walking in Chronic Motor-incomplete Paraplegia: A Case Series. | Kressler J, Domingo A | J Neurol Phys Ther. 2019 Apr;43(2):128-135 | Ekso | SCI |
| Assistive powered exoskeleton for complete spinal cord injury: correlations between walking ability and exoskeleton control | Guanziroli E, Cazzaniga M, Colombo L, Basilico S, Legnani G, Molteni F | Eur J Phys Rehabil Med. 2019 Apr;55(2):209-216 | ReWalk | SCI |
| Overground walking with a robotic exoskeleton elicits trunk muscle activity in people with high-thoracic motor-complete spinal cord injury | Alamro RA, Chisholm AE, Williams AMM, Carpenter MG, Lam T | J Neuroeng Rehabil. 2018 Nov 20;15(1):109 | Ekso | SCI |
| Exoskeleton and End-Effector Robots for Upper and Lower Limbs Rehabilitation: Narrative Review | Molteni F, Gasperini G, Cannaviello G, Guanziroli E | PM R. 2018 Sep;10(9 Suppl 2):S174-S188 | Multiple – Review Article | CVA, SCI |
| Neuromechanical adaptations during a robotic powered exoskeleton assisted walking session | Ramanujam A, Cirnigliaro CM, Garbarini E, Asselin P, Pilkar R, Forrest GF | J Spinal Cord Med. 2018 Sep;41(5):518-528 | Ekso | SCI |
| Initial Outcomes from a Multicenter Study Utilizing the Indego Powered Exoskeleton in Spinal Cord Injury | Tefertiller C, Hays K, Jones J, Jayaraman A, Hartigan C, Bushnik T and Forrest G | Top Spinal Cord Inj Rehabil. 2018 Winter;24(1):78-85 | Indego | SCI |
| Effects of Exoskeleton Training Intervention on Net Loading Force in Chronic Spinal Cord Injury | Husain SR, Ramanujam A, Momeni K, Forrest GF | Annu Int Conf IEEE Eng Med Biol Soc. 2018 Jul:2018:2793-2796 | Ekso | SCI |
| Robotic Rehabilitation and Spinal Cord Injury a Narrative Review | Mekki M, Delgado AD, Fry A, Putrino D, Huang V | Neurotherapeutics. 2018 Jul;15(3):604-617 | Multiple – Review Article | SCI |
| Mechanisms for improving walking speed after longitudinal powered robotic exoskeleton training for individuals with spinal cord injury | Ramanujam A, Momeni K, Husain SR, Augustine J, Garbarini E, Barrance P, Spungen A, Asselin P, Knezevic S, Forrest GF | Annu Int Conf IEEE Eng Med Biol Soc. 2018 Jul:2018:2805-2808 | Ekso | SCI |
| Shaping neuroplasticity by using powered exoskeletons in patients with stroke: a randomized clinical trial | Calabrò RS, Naro A, Russo M, Bramanti P, Carioti L, Balletta T, Buda A, Manuli A, Filoni S, Bramanti A. | J Neuroeng Rehabil. 2018 Apr 25;15(1):35 | Ekso | CVA |
| Exoskeleton-assisted gait training to improve gait in individuals with spinal cord injury: a pilot randomized study | Chang SH, Afzal T,  Berliner J, Francisco GE | Pilot Feasibility Stud. 2018 Mar 5:4:62 | Ekso | SCI |
| Gait training after spinal cord injury: safety, feasibility and gait function following 8 weeks of training with the exoskeletons from Ekso Bionics. | Bach Baunsgaard C, Vig Nissen U, Katrin Brust A, Frotzler A, Ribeill C, Kalke YB, León N, Gómez B, Samuelsson K, Antepohl W, Holmström U, Marklund N, Glott T, Opheim A, Benito J Murillo N, Nachtegaal J, Faber W, Biering-Sørensen F | Spinal Cord. 2018 Feb;56(2):106-116 | Ekso | SCI |
| Wearable robotic exoskeleton for over-ground gait training in sub-acute and chronic hemiparetic stroke patients: preliminary results | Molteni F, Gasperini G, Gaffuri M, Colombo M, Giovanzana C, Lorenzon C, Farina N, Cannaviello G, Scarano S, Proserpio D, Liberali D, Guanziroli E. | Eur J Phys Rehabil Med. 2017 Oct;53(5):676-684 | Ekso | CVA |
| An integrated gait rehabilitation training based on Functional Electrical Stimulation cycling and overground robotic exoskeleton in complete spinal cord injury patients: preliminary results | Mazzoleni S, Battini E, Rustici A, Stampacchia G. | IEEE Int Conf Rehabil Robot. 2017 Jul:2017:289-293 | Ekso | SCI |
| Feasibility and Safety of a Powered Exoskeleton for Assisted Walking for Persons With Multiple Sclerosis: A Single-Group Preliminary Study | Kozlowski AJ, Fabian M, Lad D, Delgado AD. | Arch Phys Med Rehabil. 2017 Jul;98(7):1300-1307 | ReWalk | MS |
| Electromechnical assisted training for walking after stroke a major update of the evidence | Mehrholz J, Thomas S, Werner C, Kugler J, Pohl M, Elsner B | Stroke. 2017 Jun 16:STROKEAHA.117.018018 | Multiple – Review Article | CVA |
| Training Response to Longitudinal Powered Exoskeleton Training for SCI | Ramanujam A, Spungen A, Asselin P, Garbarini E, Augustine J, Canton S., Barrance P., Forrest GF | Wearable Robotics: Challenges and Trends, 2017, Volume 16 | Ekso, ReWalk | SCI |
| Accelerometry-enabled measurement of walking performance with a robotic exoskeleton: a pilot study | Lonini L, Shawen N, Scanlan K, Rymer WZ, Kording KP, Jayaraman A | J Neuroeng Rehabil. 2016 Mar 31:13:35 | ReWalk | SCI |
| Effects on mobility training and de-adaptations in subjects with Spinal Cord Injury due to a Wearable Robot: a preliminary report. | Sale P, Russo EF, Russo M, Masiero S, Piccione F, Calabrò RS, Filoni S | BMC Neurol. 2016 Jan 28:16:12 | Ekso | SCI |
| Lower limb exoskeletons for individuals with chronic spinal cord injury: Findings from a feasibility study | Benson I, Hart K, van Middendorp JJ, Tussler D | Clin Rehabil. 2016 Jan;30(1):73-84 | ReWalk | SCI |
| Gait speed using powered robotic exoskeletons after spinal cord injury: a systematic review and correlational study | Louie DR, Eng JJ, Lam T | J Neuroeng Rehabil. 2015 Oct 14:12:82 | Multiple – Review Article | SCI |
| Time and Effort Required by Persons with Spinal Cord Injury to Learn to Use a Powered Exoskeleton for Assisted Walking. | Kozlowski A, Bryce TN, Dijkers MP | Top Spinal Cord Inj Rehabil. 2015 Spring;21(2):110-21 | Ekso | SCI |
| Assessment of In-Hospital Walking Velocity and Level of Assistance in a Powered Exoskeleton in Persons with Spinal Cord Injury | Yang A, Asselin P, Knezevic S, Kornfeld S, Spungen AM | Top Spinal Cord Inj Rehabil. 2015 Spring;21(2):100-9 | ReWalk | SCI |
| Mobility Outcomes Following Five Training Sessions with a Powered Exoskeleton | Hartigan C, Kandilakis C, Dalley S, Clausen M, Wilson E, Morrison S, Etheridge S, Farris R. | Top Spinal Cord Inj Rehabil. 2015 Spring;21(2):93-9 | Indego | SCI |
| Acute Cardiorespiratory and Metabolic Responses During Exoskeleton-Assisted Walking Overground Among Persons with Chronic Spinal Cord Injury | Evans N, Hartigan C, Kandilakis C, Pharo E, Clesson I | Top Spinal Cord Inj Rehabil. 2015 Spring;21(2):122-32 | Indego | SCI |
| Understanding Therapeutic Benefits of Overground Bionic Ambulation: Exploratory Case Series in Persons With Chronic, Complete Spinal Cord Injury | Kressler J, Thomas CK, Field-Fote EC, Sanchez J, Widerström-Noga E, Cilien DC, Gant K, Ginnety K, Gonzalez H, Martinez A, Anderson KD, Nash MS | Arch Phys Med Rehabil. 2014 Oct;95(10):1878-1887.e4 | Ekso | SCI |
| A preliminary assessment of legged mobility provided by a lower limb exoskeleton for persons with paraplegia | Farris RJ, Quintero HA, Murray SA, Ha KH, Hartigan C, Goldfarb M | IEEE Trans Neural Syst Rehabil Eng. 2014 May;22(3):482-90 | Indego | SCI |
| The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-level motor-complete spinal cord injury | Esquenazi A, Talaty M, Packel A, Saulino M | Am J Phys Med Rehabil. 2012 Nov;91(11):911-21 | ReWalk | SCI |
| Safety and tolerance of the ReWalkTM exoskeleton suit for ambulation by people with complete spinal cord injury: a pilot study. | Zeilig G, Weingarden H, Zwecker M, Dudkiewicz I, Bloch A, Esquenazi A. | J Spinal Cord Med. 2012 Mar;35(2):96-101 | ReWalk | SCI |
| Preliminary evaluation of a powered lower limb orthosis to aid walking in paraplegic individuals | Farris RJ, Quintero HA, Goldfarb M | IEEE Trans Neural Syst Rehabil Eng. 2011 Dec;19(6):652-9 | Indego | SCI |

ABI = acquired brain injury, CVA = stroke, MS = multiple sclerosis, SCI = spinal cord injury