Function

There are a number of articles that assess functional changes in participants. The majority of the articles looked at a population with stroke (27 articles) or spinal cord injury (22 articles). These publications are fairly evenly split between case series (17 articles), randomized controlled trials (12 articles), and review articles (13 articles). Fourteen articles assessed function using the Walking Index for Spinal Cord Injury (WISCI-II), 17 utilized the functional ambulation category (FAC), 18 used the Functional Independence Measure (FIM), and 8 used the Rivermead Mobility Index. Review articles examined articles utilizing many devices. Most other studies utilized the Ekso1.1/GT/NR device, referred to as "Ekso" in this paper.

Studies Completed in Inpatient Rehabilitation

While some studies were completed in a true research environment, numerous articles summarize trials or analysis that were completed with patients in inpatient rehabilitation. This is important because many research trials utilize dosages that are unrealistic in an insurance-based healthcare system.

A randomized controlled trial was conducted at 3 inpatient rehabilitation hospitals with participants with subacute stroke who were unable to walk without assistance. Nineteen of the 36 patients were randomized to replace 3 physical therapy sessions per week with Ekso gait training. Analysis was completed both per-protocol and as-treated, as there were 5 participants assigned to receive Ekso training that did not receive the protocol as planned.[1] When assessed as-treated, those that were treated with an exoskeleton regained independent walking in 24.1±9.7 days versus those in the control group who achieved independent walking at 35.3±15.7 days.[1] A similar study design had 29% of the Ekso group and only 8% of the control group achieving independent ambulation at the conclusion of the study period.[2] Another prospective randomized controlled trial utilized subjects with spinal cord injury admitted to an inpatient rehabilitation unit. Groups received either conventional therapy or Ekso walking plus conventional therapy and received the same amount of treatment time. Spinal Cord Independence Measure (SCIM) total score and International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) total motor and sensory scores significantly increased for the group receiving Ekso as part of their rehab.[3] These improvements were 13 points higher than the conventional therapy group on the SCIM, 14 points higher on the total motor score, and 22 points higher on the total sensory score by discharge.[3]

The bulk of studies completed during inpatient rehabilitation were retrospective, comparing medical records of patients who received some exoskeleton treatment as part of their stay with those that did not. There were varied findings, though most were in favor of exoskeleton usage. One study looked at 22 patients post-stroke who received at least 3 Ekso sessions during their length of stay and a comparison group matched with controls based on age, gender, length of stay, hemiparetic side, and admission motor FIM. Notable conclusions were regarding dosage – typical therapy sessions for both groups included walking of similar distances, however the group that received Ekso treatment walked almost double the distance total during their inpatient stay (1742.7±163.3 m versus 906.96±123.42 m).[4] Average change in motor FIM was significantly greater in the group receiving robotic training (28.3±1.5 versus 23.6±1.74).[4] In the group receiving robotic training, there was a correlation between total distance and difference in

motor FIM.[4] A similar study examining patients with SCI and CVA compared those who received usual care with those who received at least one exoskeleton session. 58% of those with SCI who received exoskeleton sessions and 56% of those with CVA who received exoskeleton sessions had 5 or more sessions, and their functional outcomes were compared with those who received usual care.[5] Statistically significant results included FIM change in patients with SCI favoring those who received Ekso treatment.[5] However, another analysis of participants with non-traumatic brain injuries compared those who received some treatment using the Ekso exoskeleton with age matched controls who received the same amount of therapy time demonstrated that while the whole sample significantly improved their FIM total, FIM subscores, level of assistance, and distance walked, when changes from admission to discharge between the two groups were compared, the only statistically significant difference between the groups were level of assistance and distance walked, both in favor of the control group.[6]

While there were no comparison groups, other retrospective patient analysis in those utilizing exoskeleton treatment was found favorable. In an analysis of 36 patients post stroke and ABI who utilized the Ekso during their rehabilitation stay, the number of robotic steps was found to be a predictor for discharge motor FIM score, with every additional 1000 robotic steps equating to an increase of 3 points on discharge motor FIM.[7] An additional study examined 25 patients who utilized the Ekso as part of their inpatient stay on either the SCI or CVA unit for an average of 4.5 sessions (range: 3-8) during their 38.5 day rehabilitation stay (range: 25.5-58.5).[8] These folks significantly improved all functional outcomes including WISCI-II, SCIM, FIM, and Stroke Rehabilitation Assessment of Movement (STREAM) from admission to discharge.[8] A retrospective review of 18 patients with SCI who utilized Ekso during their inpatient stay and continued use into outpatient therapy found that those with complete injuries improved their WISCI-II scores from 0±0 at inpatient admission to 3±4.6 by outpatient discharge, whereas the motor incomplete group demonstrated a change of 0.2±0.4 to 9.0±6.4.[9]

Two studies identified a longer length of stay for those who were treated with exoskeletons. One study identified important between-group differences for those with CVA who tended to be younger and more impaired at admission versus the usual care group.[5] This could explain why those who received exoskeleton treatment had a longer length of stay.[5] Another study that showed an increased length of stay for those using exoskeletons compared 8 patients with SCI to 16 controls and demonstrated that the change in FIM score was significantly higher in the exoskeleton group at 37.8±10.8 versus 26.5±14.3 in controls.[10] It is important to note that both of these studies were completed before lump sum payments for inpatient rehabilitation facilities in the United States were instated.

Stroke (CVA)

In patients with stroke, research studies overall were in favor of exoskeleton usage. Different devices were utilized, as were patients with varying chronicity. Pre-post studies demonstrated functional improvements in these participants. Forty-six subjects with subacute stroke participated in 15±2 sessions with Ekso with testing pre and post intervention. Of the 14 patients who were unable to walk pre-intervention, 8 regained the ability to walk post-intervention.[11] FAC and walking handicap scale also improved in this sample indicating post-intervention that participants no longer required manual assistance.[11] Another similar study showed improvements in functional ambulation classification post 15-sessions of Ekso training for eight

subacute patients, averaging a 1.88±0.64 change score[12] whereas 23 participants completing 12 Ekso sessions increased scores by 2.5 and 1 for subacute and chronic participants, respectively.[13] Similar results were found utilizing the Indego exoskeleton for four sessions in subacute patients.[14] A smaller sample of two patients within 30 days of stroke onset received Ekso training three times per week for ten weeks both improved their functional ambulation classification by 2.[15]

There are a few randomized controlled trials that favored exoskeleton usage. In a study using exoAtlet, 17 participants with subacute stroke were randomized to receive treatment with exoAtlet or conventional training for 12 sessions and only those in the exoAtlet group significantly improved their FAC while the control group remained with scores averaging 0.[16] Another study of 30 participants with chronic ischemic stroke demonstrated that the 15 subjects assigned to receive 24 sessions of gait training using Ekso improved their FIM scores by 22 points whereas those who received therapist-aided gait training only improved by 4 points.[17] Another study randomized 40 participants to gait training five times per week for 8 weeks using either Ekso or traditional overground gait training. Only those in the Ekso group met the MCID for the Rivermead index, indicating greater change from pre to post intervention.[18] Using the Rivermead and Barthel indices, 23 patients who underwent rehabilitation using the Ekso were compared to 21 patients who received conventional rehabilitation. While these groups were not equal at baseline, the exoskeleton group improved in more categories and was stronger than those receiving conventional treatment.[19]

While most studies demonstrated superiority of exoskeleton usage, one study found no statistically significant difference between groups in regards to their improvement in FAC.[20]

One study examined a high-intensity technology-assisted program for three to five sessions per week over four weeks with 14 participants post-CVA. This consisted of many types of devices for both upper and lower extremities. Each subject received an average of 46±15 sessions of technology-assisted training over the study period and FAC scores improved from 2 to 3.5.[21]

In reviews comparing patients post-stroke to a control group, participants who received training with an exoskeleton significantly improved their FAC with small effect size.[22] A large review of 34 randomized controlled trials consisting of 1166 patients confirmed this finding, with superiority of the exoskeleton group in improving FAC with a p value of 0.03 overall and 0.04 for subjects with subacute CVA, indicating significance.[23] Overground exoskeletons were more likely to promote functional independence.[23] A large review of 36 trials including 1472 participants demonstrated that using electro-mechanical assisted gait training in combination with conventional physical therapy increased the odds of participants gaining independence with walking (Odds ratio 1.94).[24] Review articles highlight the variability in studies completed on exoskeletons in regard to device, dosage, patient population, and study design.[25]

Spinal Cord Injury (SCI)

Research studies using subjects with spinal cord injuries had neutral to positive changes in function. A randomized controlled trial assigned the Ekso group (n=8) to three sessions per week for 24 weeks of Ekso gait training and the control group (n=8) to the same schedule of training consisting of resistance, cardiovascular, flexibility, overground gait training, and treadmill gait training. All participants had chronic SCI. Six (two in Ekso group) were non-ambulatory at

both baseline and conclusion of training, however, two participants in the Ekso group were able to take some steps at the conclusion of training.[26] A prospective analysis of 52 participants with SCI who completed 24 Ekso sessions utilized the SCIM-III to identify statistically significant improvement in the total score and all subscores in those who were recently injured (<1 year) and in total score of those with chronic injuries.[27] In those who were recently injured (<1 year), 20% had gait function at baseline, and this improved to 54% at the conclusion of treatment.[28] One patient in the chronically injured group moved from having no gait function to having gait function.[28] After 36 sessions of Ekso training, 55% of Ekso participants transitioned from being household to community ambulators, while none of the control participants did.[29] A case study of one patient who had a T11 chronic injury utilized the ReWalk over 6 months and went from being unable to walk to walking independently.[30] A feasibility study using the Able exoskeleton had 24 participants with mostly subacute SCI walking in the device for 12 sessions over 4 weeks. At the conclusion of training, the average WISCI score improved from 4.417 to 6.045 out of a possible 20, with 11 of the 22 subjects who had baseline and post-intervention testing showing improvements.[31] SCIM mobility scores were taken at baseline and at a 4 week follow up for all 24 subjects, and the average SCIM mobility score (out of 40) improved from 16.708 to 19.208.[31] Total SCIM scores showed a similar trend of improvement from a median of 68 to 72.5 out of 100.[31]

In comparison, one study did not show any functional changes after using exoskeletons. A pre-post study looking at 7 participants with SCI showed no difference in SCIM scores after exoskeleton walking with the Ekso, however these participants averaged a score of 68.00±7.53 out of a possible 100, so the lack of improvement may have been due to the higher independence level at baseline.[32]

Four review articles looked at a large variety of overground and treadmill based robotic devices in the SCI population. One meta-analysis largely looking at Lokomat studies showed superiority using robotics for Lower Extremity Motor Score (LEMS) improvement and FIM.[33] Acute patients with SCI showed greater improvement in LEMS and WISCI-II than those who received conventional treatment.[34] WISCI-II also improved more in exoskeleton treated patients versus those receiving conventional treatment for those with SCI of any level.[35]

A unique review article looking at 19 studies using subjects with SCI aimed to determine the dosage required to see improvements. 60-min sessions offered 3 times a week for 8 weeks was the determined duration required for functional restoration, though it is important to note that most of these studies were completed in a research environment that is able to provide care for much longer than typical under an insurance-based healthcare system.[36]

Multiple Sclerosis (MS)

Four articles specifically examine function in patients with MS. These articles utilized small sample sizes and grossly did not show between group differences when comparing functional improvements from conventional treatment versus treatment with an exoskeleton.[37] Other studies were not comparative but showed improvement in functional scales after exoskeleton usage.[38] In one study, a group was treated with the Ekso device and the control group received conventional physical therapy. While not reaching levels of statistical significance, a trend

toward improvement was observed in favor of the Ekso group for the time per group interaction in the total short physical performance battery score.[39]

Acquired Brain Injury

One unique article examines the use of the Ekso device on patients with severe brain injuries who had a score of 3 or less on the motor portion of the Coma Recovery Scale (localization to noxious stimulation). Ten patients completed an average of 10.4±4.8 overground exoskeleton sessions as part of their inpatient rehabilitation stay. After an average rehabilitation stay of 47.3 days, they improved their Disability Rating Scale score from 21.9 to 18.1 where a lower score indicates less disability.[40]

Review Articles

A review article looking at both SCI and CVA populations examined 15 lower extremity review articles and 8 upper extremity review articles highlighted the heterogeneity in the literature which makes drawing sweeping conclusions next to impossible. This heterogeneity is in both device type and function as well as in the duration of a single session and global period of treatment.[41]

Conclusion

There is a significant amount of literature that focuses on functional changes resulting from using an exoskeleton. Overall, using an exoskeleton helps to improve function in patients with a variety of neurological diagnoses, though this is not unanimous. A number of functional measures are utilized in the literature which may also measure somewhat different things. Some articles report a specific subscore of an outcome measure, while another article may use the total score. All of this, in addition to the variety of devices and dosage of the intervention reported in the literature, makes drawing a sweeping conclusion difficult.

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All known articles assessing function in participants using an exoskeleton

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
Robotic locomotor training in a low-resource setting: a randomized pilot and feasibility trial	Shackleton C, Evans R, West S, Bantjes J, Swartz L, Derman W, Albertus Y	Disabil Rehabil. 2024 Jul;46(15):3363-3372	Ekso	SCI
Feasibility of overground exoskeleton gait training during inpatient rehabilitation after severe acquired brain injury	Gillespie J, Trammell M, Ochoa C, Driver S,Callender L, Dubiel R, Swank C	Brain Inj. 2024 May 11;38(6):459-466	Ekso	ABI
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
Exoskeletal-Assisted Walking During Acute Inpatient Rehabilitation Enhances Recovery for Persons with Spinal Cord Injury-A Pilot Randomized Controlled Trial	Tsai Cy, Weinrauch WJ, Manente N, Huang V, Bryce TN, Spungen AM	J Neurotrauma. 2024 May 8. doi: 10.1089/neu.2023.0667	Ekso	SCI
Clinical Delivery of Overground Exoskeleton Gait Training in Persons With Spinal Cord Injury Across the Continuum of Care: A Retrospective Analysis	Arnold D, Gillespie J, Bennett M, Callender L, Sikka S, Hamilton R, Driver S,Swank C	Top Spinal Cord Inj Rehabil. 2024 Winter;30(1):74-86	Ekso	SCI
Effects of robotic-assisted gait training on physical capacity, and quality of life among chronic stroke patients: A randomized controlled study	Bodur BE, Erdoğanoğlu Y, Sel SA	J Clin Neurosci. 2024 Jan 18:120:129-137	Exoatlet, lokomat	CVA
Impact of Robotic-Assisted Gait Therapy on Depression and Anxiety Symptoms in Patients with Subacute Spinal Cord Injuries (SCIs)—A Prospective Clinical Study	Widuch-Spodyniuk A, Tarnacka B, Korczy ́nski B, Wi ́sniowska J	J Clin Med. 2023 Nov 17;12(22):7153	Ekso, Lokomat	SCI
Overground Robotic Exoskeleton Training for Patients With Stroke on Walking-Related Outcomes: A Systematic Review and Meta-analysis of Randomized Controlled Trials	Leow XRG, Ng SLA, Lau Y	Arch Phys Med Rehabil. 2023 Oct;104(10):1698-1710	Multiple – Review Article	CVA

All known articles assessing function in participants using an exoskeleton

Title	Authors	Journal	Device	Diagnosis
Retrospective case-control study to compare exoskeleton-assisted walking with standard care in subacute non-traumatic brain injury patients	Tosto-Mancuso J, Rozanski G, Patel N, Breyman E, Dewil S, Jumreornvong O, Putrino D, Tabacof L, Escalon M, Cortes M	NeuroRehabilitation. 2023;53(4):577-584	Ekso	ABI
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	Lokomat, Ekso, AIDER	SCI
Enhanced Rehabilitation Outcomes of Robotic-Assisted Gait Training with EksoNR Lower Extremity Exoskeleton in 19 Stroke Patients	Wiśniowska-Szurlej A, Wołoszyn N, Brożonowicz J, Ciąpała G, Pietryka K, Grzegorczyk J, Leszczak J, Ćwirlej-Sozańska A, Sozański B, Korczowski B	Med Sci Monit. 2023 Jul 15:29:e940511	Ekso	CVA
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
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, Carnicero-Carmona A, Lobo-Prat J, Hensel C, Franz S, Weidner N, Vidal J, Opisso E, Rupp R	J Neuroeng Rehabil. 2023 Apr 12;20(1):45	Able	SCI
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

All known articles assessing function in participants using an exoskeleton

Title	Authors	Journal	Device	Diagnosis
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
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
Implementing the exoskeleton Ekso GT for gait rehabilitation in a stroke unit – feasibility, functional benefits and patient experiences	Høyer E, Opheim A, Jørgensen V	Disabil Rehabil Assist Technol. 2022 May;17(4):473-479	Ekso	CVA
Brain Network Organization Following Post-Stroke Neurorehabilitation	Naro A, Pignolo L, Calabrò RS	Int J Neural Syst. 2022 Apr;32(4):2250009.	Ekso	CVA
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
Robotic Exoskeleton Gait Training in Stroke: An Electromyography-Based Evaluation	Longatelli V, Pedrocchi A, Guanziroli E, Molteni F, Gandolla M	Front Neurorobot. 2021 Nov 26:15:733738.	Ekso	CVA

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Title	Authors	Journal	Device	Diagnosis
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
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, Francisco GE	Front Neurorobot. 2021 Sep 1:15:689363.	Indego	CVA
Wearable Robotic Gait Training in Persons with Multiple Sclerosis: A Satisfaction Study	Fernández-Vázquez D, Cano-de-la-Cuerda R, Dolores Gor-García-Fogeda M, Molina-Rueda F	Sensors (Basel). 2021 Jul 20;21(14):4940	Ekso	MS
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
Predictors of functional outcome in a cohort of Hispanic patients using exoskeleton rehabilitation for cerebrovascular accidents and traumatic brain injury	Treviño LR, Roberge P, Auer ME, Morales A, Torres-Reveron A;	Front Neurorobot. 2021 Jun 10:15:682156	Ekso	CVA, ABI
Can powered exoskeletons improve gait and balance in multiple sclerosis? A retrospective study	Russo M, Grazia Maggio M, Naro A, Portaro S, Porcari B, Balletta T, De Luca R, Raciti L, Calabrò RS	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	Berriozabalgoitia R, Bidaurrazaga-Letona I, 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
Enhancing quality of life in progressive multiple sclerosis with powered robotic exoskeleton	Wee SK, Ho CY, Tan SL, Ong CH	Mult Scler. 2021 Mar;27(3):483-487	Ekso	MS

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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
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, Grazia Maggio M, Portaro S, Naro A, Calabrò RS	J Clin Neurosci. 2020 Nov:81:240-245	Ekso	CVA
Robotic Exoskeleton Gait Training During Acute Stroke Inpatient Rehabilitation	Nolan KJ, Karunakaran KK, Chervin K, Monfett MR, Bapineedu RK, Jasey NN, Oh-Park M	Front Neurorobot. 2020 Oct 30:14:581815	Ekso	CVA
Electromechanical assisted training for walking after stroke	Mehrholz J, Thomas S, Werner C, Kugler J, Pohl M, Elsner B	Cochrane Database Syst Rev. 2020 Oct 22;10(10):CD006185	Multiple – Review Article	CVA
The utilization of an overground robotic exoskeleton for gait training during inpatient rehabilitation-single-center retrospective findings.	Swank C, Trammell M, Bennett M, Ochoa C, Callender L, Sikka S, Driver S.	Int J Rehabil Res. 2020 Sep;43(3):206-213	Ekso	SCI, 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, Lokomat	SCI
Feasibility of integrating robotic exoskeleton gait training in inpatient rehabilitation.	Swank C, Sikka S, Driver S, Bennett M, Callender L.	Disabil Rehabil Assist Technol. 2020 May;15(4):409-417	Ekso	SCI, CVA
Exoskeletal-Assisted Walking during Acute Inpatient Rehabilitation Leads to Motor and Functional Improvement in Persons with Spinal Cord Injury - a Pilot Study.	Tsai CY, Delgado AD, Weinrauch WJ, Manente N, Levy I, Escalon MX, Bryce TN, Spungen AM.	Arch Phys Med Rehabil. 2020 Apr;101(4):607-612	Ekso	SCI
Effects of Exoskeleton Gait Training on Balance, Load Distribution, and Functional Status in Stroke: A Randomized Controlled Trial	Rojek A, Mika A, Oleksy L, Stolarczyk A, Kielnar R	Front Neurol. 2020 Jan 15:10:1344.	Ekso	CVA
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

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Exoskeleton Gait Training After Spinal Cord Injury: An Exploratory Study on Secondary Health Conditions	Baunsgaard CBB, Vig Nissen U, Brust AK, Frotzler A, Ribeill C, Kalke YB, León N, Gómez B, Samuelsson K, Antepohl W, Holmström U, Marklund N, Glott T, Opheim A, Penalva JB, Murillo N, Nachtegaal J, Faber W, Biering-Sørensen F	J Rehabil Med. 2018 Sep 28;50(9):806-813	Ekso	SCI
Narrative Review of Exoskeleton and End-Effector Robots	Molteni F, Gasperini G, Cannaviello G, Guanziroli E	PM R. 2018 Sep;10(9 Suppl 2):S174-S188	Multiple – Review Article	SCI, CVA
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
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
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
Effects of training with the ReWalk exoskeleton on quality of life in incomplete spinal cord injury: a single case study	Raab K, Krakow K, Tripp F and Jung M	Spinal Cord Ser Cases. 2016 Jan 7:2:15025	ReWalk	SCI

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