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Robotic-Assisted Gait Training for Children With Cerebral Palsy

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Summary of Abstracts

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About CADTH: CADTH is an independent, not-for-profit organization responsible for providing Canada's health care decision-makers with objective evidence to help make informed decisions about the optimal use of drugs, medical devices, diagnostics, and procedures in our health care system.

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Key Messages

- No evidence was identified regarding the clinical effectiveness of robotic-assisted gait training (RAGT) versus no therapy for children with cerebral palsy.
- Eight randomized controlled trials and 1 non-randomized study were identified regarding the clinical effectiveness of RAGT training versus alternative therapies for children with cerebral palsy.
- No evidence was identified regarding the cost-effectiveness of RAGT versus no therapy for children with cerebral palsy.
- No evidence was identified regarding the cost-effectiveness of RAGT versus alternative therapies for children with cerebral palsy.

Research Questions

1. What is the clinical effectiveness of robotic-assisted gait training (RAGT) versus no therapy for children with cerebral palsy?
2. What is the clinical effectiveness of RAGT versus alternative therapies for children with cerebral palsy?
3. What is the cost-effectiveness of RAGT versus no therapy for children with cerebral palsy?
4. What is the cost-effectiveness of RAGT versus alternative therapies for children with cerebral palsy?

Methods

Literature Search Methods

A limited literature search was conducted by an information specialist on key resources including Medline through Ovid, Scopus, the Cochrane Database of Systematic Reviews, the International HTA Database, and the websites of Canadian and major international health technology agencies, as well as a focused internet search. The search strategy comprised both controlled vocabulary, such as the National Library of Medicine's MeSH (Medical Subject Headings), and keywords. The main search concepts were robotic assisted gait training and cerebral palsy. No filters were applied to limit the retrieval by study type. Where possible, retrieval was limited to the human population. The search was completed on June 13, 2022, and limited to English-language documents published since January 1, 2015. Internet links were provided, where available.

Selection Criteria and Summary Methods

One reviewer screened literature search results (titles and abstracts) and selected publications according to the inclusion criteria presented in Table 1. Full texts of study publications were not reviewed. The overall summary of findings was based on information available in the abstracts of selected publications.

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Table 1: Selection Criteria

Criteria	Description
Population	Children with cerebral palsy (≤ 18 years old)
Intervention	Robotic-assisted gait training
Comparator	Q1 and Q3: No treatment Q2 and Q4: Alternative therapies (e.g., physiotherapy, manual gait training, water-based therapy)
Outcomes	Q1: Clinical effectiveness (e.g., gross motor function, gait parameters, walking endurance, independence) Q2: Cost-effectiveness (e.g., incremental cost per health benefit, quality-adjusted life-years gained)
Study designs	Health technology assessments, systematic reviews, randomized controlled trials, non-randomized studies, economic evaluations

Results

Eight randomized controlled trials (RCTs)[1-8] and 1 non-randomized study[9] were identified regarding the clinical effectiveness of RAGT versus alternative therapies for children with cerebral palsy. No relevant health technology assessments, systematic reviews, or economic evaluations were identified.

Additional references of potential interest that did not meet the inclusion criteria are provided in Appendix 1.

Overall Summary of Findings

Eight RCTs[1-8] and 1 non-randomized study[9] were identified regarding the clinical effectiveness of RAGT versus alternative therapies for children with cerebral palsy. A detailed summary of these studies can be found in Table 2.

Two RCTs[1,2] compared RAGT to usual or standard care: 1 RCT[1] found no change on Gross Motor Function Measure (GMFM) or timed walking tests after either treatment, while the other[2] found RAGT was associated with improved locomotor function and functional capabilities compared to standard care. The latter study also noted that functional improvements were mainly seen in children classified as level II to III on the Gross Motor Function Classification System (GMFCS) scale, compared to those classified as level IV.[2]

Three RCTs[4-6] compared RAGT to different types of treadmill-related training programs. One RCT[4] compared robotic-assisted treadmill exercise to partial body weight–supported treadmill exercise or anti-gravity treadmill exercise, and reported they did not differ significantly on speed, gait analysis, or GMFM scores. One RCT[5] compared RAGT to treadmill only, and reported that the RAGT group had significant improvements post-intervention but the treadmill-only group did not. Another RCT[6] compared RAGT to robotic treadmill training with controlled resistance for children classified as levels I to IV on the GMFCS scale; they found that outcomes did not change significantly after RAGT, but did improve significantly following robotic treadmill training with controlled resistance.

Two RCTs[7,8] and 1 non-randomized study[9] compared RAGT to physiotherapy; all reported significant improvements in the RAGT group on locomotor parameters,[7] kinetic data,[7] kinematic data,[8] and GMFM scores[8,9] when comparing pre- and post-intervention. The non-randomized study[9] reported that no differences were observed between RAGT or task-oriented physiotherapy. The 2 RCTs[7,8] did not report between-group comparisons in the abstract.

One RCT[3] compared RAGT to non-assisted gait training for children classified as levels I to III on the GMFCS scale, and reported that RAGT was associated with improved hip angle and limb symmetry, but not gait speed.

No evidence was identified specific to children under the age of 6 with cerebral palsy classified as level V on the GMFCS scale; therefore, no summary can be provided for this specific subgroup. In addition, no relevant literature was found regarding the clinical effectiveness of RAGT compared to no treatment, or the cost-effectiveness of RAGT compared to no treatment or alternative treatments for children with cerebral palsy; therefore, no summary can be provided.

Table 2: Summary of Included Clinical Effectiveness Studies

Study citation	Study design, population	Intervention and comparator(s)	Relevant outcome(s)	Authors' conclusions
Randomized controlled trials				
Ammann-Reiffer et al. (2020)[1]	**Study design**: Randomized crossover trial **Population**: Children with spastic CP (mean age = 11.3) **N** = 16	**Intervention:** RAGT (3 sessions per week for 5 weeks) **Comparator:** Usual care (for 5 weeks)	Primary outcome: • GMFM Dimension E Secondary outcomes: • GMFM Dimension D • Timed walking tests before and after each treatment sequence and after a 5-week follow-up	No outcomes changed significantly after RAGT or usual care, and there were no period, follow-up, or carry-over effects observed.
Jin et al. (2020)[2]	**Study design**: Single-centre, single-blinded randomized crossover trial **Population**: Children with CP (GMFCS II to IV, age range = 6.75 ± 2.15 years) **N** = 20	**Intervention:** RAGT (Walkbot-K system, 3 sessions per week for 6 weeks) **Comparator:** Standard care (2 to 4 sessions for 6 weeks)	• GMFM score • WeeFIM • COPM score	RAGT led to benefits in locomotor function and functional capability for daily activities. Factors associated with functional improvements were mainly observed in children classified as levels II to III (GMFCS), compared to those at level IV.

Study citation	Study design, population	Intervention and comparator(s)	Relevant outcome(s)	Authors' conclusions
Kawasaki et al. (2020)[3]	**Study design**: RCT **Population**: Children with spastic CP (GMFCS I to III) **N** = 10	**Intervention:** RAGT **Comparator:** Non-assisted gait training	• Maximum hip angle • Limb symmetry • Gait speed	Limb symmetry improved significantly after RAGT but not in the comparator group. RAGT was also associated with improved maximum hip flexion and extension angle. There was no change in gait speed.
Aras et al. (2019)[4]	**Study design**: RCT **Population**: Children with spastic CP (mean age = 9.3 ± 2.3; age range = 6 to 14) **N** = 29	**Intervention:** RATE **Comparator:** PBWSTE, ATE	• Three-dimensional gait analysis • Open-circle indirect calorimeter • 6MWT • GMFM scale	The ATE and RATE groups had significantly improved oxygen consumption, but not the PBWSTE group. There was no statistically significant change compared to baseline on walking speed or gait analysis after treatment, or between groups on GMFM-D, GMFM-E, and 6MWT.
Wu et al. (2017)[5]	**Study design**: RCT **Population**: Children with CP **N** = 23	**Intervention:** Robotic-assisted treadmill training (3 times per week for 6 weeks) **Comparator:** Treadmill training only (manual assistance provided as needed; 3 times per week for 6 weeks)	• Walking speed • Six-minute walking distance	A greater increase in 6-minute walking distance was seen after robotic training compared to treadmill-only training. The robotic group saw significant increases in walking speed and 6-minute walking distance. No significant change was seen after treadmill-only training.
Wu et al. (2017)[6]	**Study design**: RCT **Population**: Children with spastic CP (mean age = 10.6; age range = 6 to 14; GMFCS I to IV) **N** = 23	**Intervention:** Robotic treadmill training with controlled assistance (3x per week for 6 weeks) **Comparator:** Robotic treadmill training with controlled resistance	• Overground walking speed • Six-minute walk distance • GMFM scores	Overground gait speed and 6-minute walk distance did not change significantly after robotic assistance training; both outcomes improved significantly after resistance training, and was still significantly greater 8 weeks after training.
Randomized controlled trials with between-group comparison not presented in abstract				
Wallard et al. (2018)[7]	**Study design**: RCT **Population**: Children with CP **N** = 36	**Intervention:** RAGT (Lokomat; 20 sessions) **Comparator:** Physiotherapy	• Locomotor parameters • Kinetic data	Significant differences were seen for the treatment group pre- and post-intervention.

Study citation	Study design, population	Intervention and comparator(s)	Relevant outcome(s)	Authors' conclusions
Wallard et al. (2017)[8]	**Study design**: RCT **Population**: Children with bilateral spastic CP **N** = 30	**Intervention:** RAGT (20 sessions with Lokomat) **Comparator:** Physiotherapy (daily)	• Kinematic data • GMFM-D and GMFM-E	Significant improvements were observed between the treatment group pre- and post-values for both outcomes.
Non-randomized studies				
Peri et al. (2017)[9]	**Study design**: NRS **Population**: Children with CP (age 4 to 17) **N** = 44	**Intervention:** RAGT (4 per week for 10 weeks) **Comparator:** • RAGT + TOP (2 + 2 per week for 10 weeks) • RAGT + TOP (5 + 5 sessions per week for 4 weeks) • TOP alone (4 per week for 10 weeks)	• GMFM-88 • GMFM-E • GMFM-66	No differences across the 4 protocols were highlighted. Mixed approaches (RAGT + TOP) did not show significant changes, while the RAGT- or TOP-only protocols saw significant improvements. RAGT seems to have similar effects to TOP over 10 weeks.

6MWT = 6-minute walk test; ATE = anti-gravity treadmill exercise; COPM = Canadian occupational performance measure; CP = cerebral palsy; GMFCS = Gross Motor Function Classification System; GMFM = Gross Motor Function Measure; NRS = non-randomized study; PBWSTE = Partial body weight–supported treadmill exercise; RAGT = robotic-assisted gait training; RATE = Robotic-assisted treadmill exercise; RCT = randomized controlled trial; TOP = task-oriented physiotherapy; WeeFIM = pediatric Functional Independence Measure.

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References

Health Technology Assessments

No literature identified.

Systematic Reviews

No literature identified.

Randomized Controlled Trials

Comparator — Alternative Therapies

1. Ammann-Reiffer C, Bastiaenen CHG, Meyer-Heim AD, van Hedel HJA. Lessons learned from conducting a pragmatic, randomized, crossover trial on robot-assisted gait training in children with cerebral palsy (PeLoGAIT). *J Pediatr Rehabil Med*. 2020; 13(2): 137-148. PubMed

2. Jin LH, Yang SS, Choi JY, Sohn MK. The effect of robot-assisted gait training on locomotor function and functional capability for daily activities in children with cerebral palsy: a single-blinded, randomized cross-over trial. *Brain Sci*. Oct 30 2020; 10(11): 30. PubMed

3. Kawasaki S, Ohata K, Yoshida T, Yokoyama A, Yamada S. Gait improvements by assisting hip movements with the robot in children with cerebral palsy: a pilot randomized controlled trial. *J Neuroengineering Rehabil*. 2020; 17(1): 87. PubMed

4. Aras B, Yasar E, Kesikburun S, Turker D, Tok F, Yilmaz B. Comparison of the effectiveness of partial body weight-supported treadmill exercises, robotic-assisted treadmill exercises, and anti-gravity treadmill exercises in spastic cerebral palsy. *Turk J Phys Med Rehabil.* 2019 Jun;65(4):361-370. PubMed

5. Wu M, Kim J, Arora P, Gaebler-Spira DJ, Zhang Y. Effects of the integration of dynamic weight shifting training into treadmill training on walking function of children with cerebral palsy: a randomized controlled study. *Am J Phys Med Rehabil*. Nov 2017; 96(11): 765-772. PubMed

6. Wu M, Kim J, Gaebler-Spira DJ, Schmit BD, Arora P. Robotic resistance treadmill training improves locomotor function in children with cerebral palsy: a randomized controlled pilot study. *Arch Phys Med Rehabil*. 2017; 98(11): 2126-2133. PubMed

Between-Group Comparison Not Presented in Abstract

7. Wallard L, Dietrich G, Kerlirzin Y, Bredin J. Effect of robotic-assisted gait rehabilitation on dynamic equilibrium control in the gait of children with cerebral palsy. *Gait Posture*. 2018; 60: 55-60. PubMed

8. Wallard L, Dietrich G, Kerlirzin Y, Bredin J. Robotic-assisted gait training improves walking abilities in diplegic children with cerebral palsy. *Europ J Paediatr Neurol*. May 2017; 21(3): 557-564. PubMed

Non-Randomized Studies

Comparator — Alternative Therapies

9. Peri E, Turconi AC, Biffi E, et al. Effects of dose and duration of Robot-Assisted Gait Training on walking ability of children affected by cerebral palsy. *Technol Health Care*. 2017; 25(4): 671-681. PubMed

Economic Evaluations

No literature identified.

Appendix 1: References of Potential Interest

Previous CADTH Reports

10. Upper and lower extremity robotic therapy and assistive devices for pediatric patients with complex developmental disabilities, brain injury, or complex pain disorders: clinical effectiveness, cost-effectiveness, and guidelines. (Rapid response report: summary of abstracts). Ottawa: CADTH, 2015. https://www.cadth.ca/sites/default/files/pdf/htis/june-2015/RB0875%20Upper%20and%20Lower%20Extremity%20Robotics%20Final.pdf Accessed 2022 Jun 15.

Systematic Reviews

Mixed Population — Not Specific to Children

11. Conner BC, Remec NM, Lerner ZF. Is robotic gait training effective for individuals with cerebral palsy? A systematic review and meta-analysis of randomized controlled trials. *Clin Rehabil*. Jul 2022; 36(7): 873-882. PubMed

12. Bunge LR, Davidson AJ, Helmore BR, et al. Effectiveness of powered exoskeleton use on gait in individuals with cerebral palsy: a systematic review. *PLoS One*. 2021; 16(5): e0252193. PubMed

13. Selph SS, Skelly AC, Wasson N, et al. Physical activity and the health of wheelchair users: a systematic review in multiple sclerosis, cerebral palsy, and spinal cord injury. *Arch Phys Med Rehabil*. 12 2021; 102(12): 2464-2481.e33. PubMed

Unclear Intervention and Participant Age Group

14. Conner BC, Remec NM, Michaels CM, Wallace CW, Andrisevic E, Lerner ZF. Relationship between ankle function and walking ability for children and young adults with cerebral palsy: A systematic review of deficits and targeted interventions. *Gait Posture*. 2022; 91: 165-178. PubMed

15. Chiu HC, Ada L, Bania TA. Mechanically assisted walking training for walking, participation, and quality of life in children with cerebral palsy. Cochrane Database Syst Rev. 2020 Nov 18;11(11):CD013114. doi: 10.1002/14651858.CD013114.pub2. PubMed: ; https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD013114.pub2/full Accessed 2022 Jun 16.

Unclear Comparator

16. Llamas-Ramos R, Sanchez-Gonzalez JL, Llamas-Ramos I. Robotic systems for the physiotherapy treatment of children with cerebral palsy: a systematic review. *Int J Environ Res Public Health*. 2022; 19(9): 22. PubMed

17. Cumplido C, Delgado E, Ramos J, et al. Gait-assisted exoskeletons for children with cerebral palsy or spinal muscular atrophy: a systematic review. *NeuroRehabilitation*. 2021; 49(3): 333-348. PubMed

18. Valè N, Gandolfi M, Vignoli L, et al. Electromechanical and robotic devices for gait and balance rehabilitation of children with neurological disability: a systematic review. *Applied Sciences (Switzerland)*. 2021; 11(24).

19. Morsy SE, Salem EE, Elhadidy EI. Effect of automated locomotor training on gait in children with cerebral palsy: a systematic review and meta-analysis. *World J Sport Sci*. 2019. 14(2): 34-41. https://idosi.org/wjss/14(2)19/2.pdf Accessed 2022 Jun 15.

Before-After Comparison

20. Lefmann S, Russo R, Hillier S. The effectiveness of robotic-assisted gait training for paediatric gait disorders: systematic review. *J Neuroengineering Rehabil*. 2017; 14(1): 1. PubMed

Before-After Comparison and Mixed Population — Not Specific to Children

21. Volpini M, Aquino M, Holanda AC, Emygdio E, Polese J. Clinical effects of assisted robotic gait training in walking distance, speed, and functionality are maintained over the long term in individuals with cerebral palsy: a systematic review and meta-analysis. *Disabil Rehabil*. 2021: 1-11. PubMed

22. Carvalho I, Pinto SM, Chagas DDV, Praxedes Dos Santos JL, de Sousa Oliveira T, Batista LA. Robotic gait training for individuals with cerebral palsy: a systematic review and meta-analysis. *Arch Phys Med Rehabil*. 2017; 98(11): 2332-2344. PubMed

Full Text Published in Spanish

23. Colomera JA, Nahuelhual P. Effectiveness of robotic assistance for gait training in children with cerebral palsy. a systematic review [article in Spanish]. *Rehabilitacion*. 2020; 54(2): 107-115. PubMed

Before-After Comparison and Full Text Published in Spanish

24. Cañadas Martinez LE, Montero Mendoza S. Effectiveness of automatic walking systems in children with cerebral palsy: A systematic review [article in Spanish]. *Fisioterapia*. 2020; 42(2): 75-84.

Randomized Controlled Trials

Mixed Population — Not Specific to Children

25. Klobucka S, Klobucky R, Kollar B. Effect of robot-assisted gait training on motor functions in adolescent and young adult patients with bilateral spastic cerebral palsy: a randomized controlled trial. *NeuroRehabilitation*. 2020; 47(4): 495-508. PubMed

Alternative Intervention — RAGT With Physiotherapy

26. Pool D, Valentine J, Taylor NF, Bear N, Elliott C. Locomotor and robotic assistive gait training for children with cerebral palsy. *Dev Med Child Neurol*. 2021; 63(3): 328-335. PubMed

27. Yaśar B, Atlcl E, Razaei DA, Saldlran TÇ. Effectiveness of robot-assisted gait training on functional skills in children with cerebral palsy. *J Pediatr Neurol*. 2021.

28. Mahgoub MSE, Amin WW, Zahran SS. Effect of locomotor training with a roboticgait orthosis (Lokomat) in spasticity modulation of spastic hemiplegic children: a randomized controlled trial. *Fizjoterapia Polska*. 2020; 20(4): 94-101.

Alternative Intervention — RAGT With Virtual Reality

29. Fu WS, Wu BA, Song YC, Qu CH, Zhao JF. Virtual reality combined with robot-assisted gait training to improve walking ability of children with cerebral palsy: a randomized controlled trial. *Technol Health Care.* May 23 2022. PubMed

Alternative Intervention — Motor-Assisted Cycle

30. Damiano DL, Stanley CJ, Ohlrich L, Alter KE. Task-specific and functional effects of speed-focused elliptical or motor-assisted cycle training in children with bilateral cerebral palsy: randomized clinical trial. *Neurorehabil Neural Repair*. Aug 2017; 31(8): 736-745. PubMed

Non-Randomized Studies

Mixed Population — Not Specific to Cerebral Palsy

31. Hong J, Lee J, Choi T, et al. Feasibility of overground gait training using a joint-torque-assisting wearable exoskeletal robot in children with static brain injury. *Sensors (Basel)*. May 19 2022; 22(10): 19. PubMed

Alternative Intervention — Robotic-Assisted Gait Therapy With Physiotherapy

32. Abidin N, Unlu Akyuz E, Cankurtaran D, Karaahmet OZ, Tezel N. The effect of robotic rehabilitation on posture and trunk control in non-ambulatory cerebral palsy. *Assist Technol*. May 05 2022; 1-7. PubMed

33. Yazici M, Livanelioglu A, Gucuyener K, Tekin L, Sumer E, Yakut Y. Effects of robotic rehabilitation on walking and balance in pediatric patients with hemiparetic cerebral palsy. *Gait Posture*. 2019; 70: 397-402. PubMed

Alternative Intervention — RAGT With Botulinum Therapy

34. Balgayeva M, Bulekbayeva S. Effectiveness of the combined use of robotic kinesiotherapy and botulinum therapy in the complex rehabilitation of children with cerebral palsy. *Asian J Pharm Clin Res*. 2018; 11(9): 360-364.

Single-Arm Studies

35. Klobucka S, Klobucky R, Kollar B. The effect of patient-specific factors on responsiveness to robot-assisted gait training in patients with bilateral spastic cerebral palsy. *NeuroRehabilitation*. 2021; 49(3): 375-389. PubMed

36. Manikowska F, Brazevic S, Krzyzanska A, Jozwiak M. Effects of robot-assisted therapy on gait parameters in pediatric patients with spastic cerebral palsy. *Front Neurol*. 2021; 12: 724009. PubMed

37. Manikowska F, Krzyzanska A, Chmara P, Chen BP, Jozwiak M. Baseline gross motor function affects the outcome of robot-assisted therapy in ambulatory individuals with spastic cerebral palsy. *Brain sci*. Nov 26 2021; 11(12): 26. PubMed

38. Petrarca M, Frascarelli F, Carniel S, et al. Robotic-assisted locomotor treadmill therapy does not change gait pattern in children with cerebral palsy. *Int J Rehabil Res*. 2021; 44(1): 69-76. PubMed

39. Zarkovic D, Sorfova M, Tufano JJ, et al. Gait changes following robot-assisted gait training in children with cerebral palsy. *Physiol Res*. 2021; 70(S3): S397-S408. PubMed

40. Cherni Y, Ballaz L, Lemaire J, Dal Maso F, Begon M. Effect of low dose robotic-gait training on walking capacity in children and adolescents with cerebral palsy. *Neurophysiol Clin*. Nov 2020; 50(6): 507-519. PubMed

41. Nakagawa S, Mutsuzaki H, Mataki Y, et al. Safety and immediate effects of Hybrid Assistive Limb in children with cerebral palsy: a pilot study. *Brain Dev*. Feb 2020; 42(2): 140-147. PubMed

42. Sucuoglu H. Effects of robot-assisted gait training alongside conventional therapy on the development of walking in children with cerebral palsy. *J Pediatr Rehabil Med*. 2020; 13(2): 127-135. PubMed

43. Zarkovic D, Sorfova M, Tufano JJ, et al. Effect of robot-assisted gait training on selective voluntary motor control in ambulatory children with cerebral palsy. *Indian Pediatr*. 10 15 2020; 57(10): 964-966. PubMed
    This pilot study investigated the efficacy of a 4-week robot-assisted gait training in 12 children with spastic diparesis. Short-term results and a 3-month follow-up showed statistically significantly increased selective motor control, walking farther distances, gross motor score, and decreased joint contractures.

44. Aycardi LF, Cifuentes CA, Munera M, et al. Evaluation of biomechanical gait parameters of patients with cerebral palsy at three different levels of gait assistance using the CPWalker. *J Neuroengineering Rehabil*. 2019; 16(1): 15. PubMed

45. Digiacomo F, Tamburin S, Tebaldi S, et al. Improvement of motor performance in children with cerebral palsy treated with exoskeleton robotic training: A retrospective explorative analysis. *Restor Neurol Neurosci*. 2019; 37(3): 239-244. PubMed

46. Lee SJ, Jin D, Kang SH, Gaebler-Spira D, Zhang LQ. Combined ankle/knee stretching and pivoting stepping training for children with cerebral palsy. *IEEE Trans Neural Syst Rehabil Eng*. 2019; 27(9): 1743-1752. PubMed

47. Weinberger R, Warken B, Konig H, et al. Three by three weeks of robot-enhanced repetitive gait therapy within a global rehabilitation plan improves gross motor development in children with cerebral palsy - a retrospective cohort study. *Europ J Paediatr Neurol*. Jul 2019; 23(4): 581-588. PubMed

48. Bayon C, Martin-Lorenzo T, Moral-Saiz B, et al. A robot-based gait training therapy for pediatric population with cerebral palsy: goal setting, proposal and preliminary clinical implementation. *J Neuroengineering Rehabil*. 2018; 15(1): 69. PubMed

49. Kang J, Martelli D, Vashista V, Martinez-Hernandez I, Kim H, Agrawal SK. Robot-driven downward pelvic pull to improve crouch gait in children with cerebral palsy. *Science Robotics*. 2017;2(8). PubMed

50. Bayon C, Lerma S, Ramirez O, et al. Locomotor training through a novel robotic platform for gait rehabilitation in pediatric population: short report. *J Neuroengineering Rehabil*. 2016; 13(1): 98. PubMed

51. Wu M, Landry JM. Toward flexible assistance for locomotor training: design and clinical testing of a cable-driven robot for stroke, spinal cord injury, and cerebral palsy. In: Reinkensmeyer D, Dietz V, eds. *Neurorehabilitation Technology* 2nd ed. Cham (Switzerland): Springer; 2016.

Single-Arm Studies and Mixed Population — Not Specific to Children

52. Fang Y, Orekhov G, Lerner ZF. Adaptive ankle exoskeleton gait training demonstrates acute neuromuscular and spatiotemporal benefits for individuals with cerebral palsy: a pilot study. *Gait Posture*. 2022 Jun;95:256-263. PubMed

53. Fang Y, Lerner ZF. Feasibility of augmenting ankle exoskeleton walking performance with step length biofeedback in individuals with cerebral palsy. *IEEE Trans Neural Syst Rehabil Eng*. 2021; 29(): 442-449. PubMed

54. Klobucka S, Klobucky R, Kollar B. The effect of patient-specific factors on responsiveness to robot-assisted gait training in patients with bilateral spastic cerebral palsy. *NeuroRehabilitation*. 2021; 49(3): 375-389. PubMed

55. Mataki Y, Mutsuzaki H, Kamada H, et al. Effect of the hybrid assistive limb on the gait pattern for cerebral palsy. *Medicina (Kaunas)*. Dec 07 2020; 56(12): 07. PubMed

56. Orekhov G, Fang Y, Luque J, Lerner ZF. Ankle exoskeleton assistance can improve over-ground walking economy in individuals with cerebral palsy. *IEEE Trans Neural Syst Rehabil Eng*. 2020 02;28(2):461-467. PubMed

57. Lerner ZF, Harvey TA, Lawson JL. A battery-powered ankle exoskeleton improves gait mechanics in a feasibility study of individuals with cerebral palsy. *Ann Biomed Eng.* 2019 Jun;47(6):1345-1356. PubMed

58. Ueno T, Watanabe H, Kawamoto H, et al. Feasibility and safety of Robot Suit HAL treatment for adolescents and adults with cerebral palsy. *J Clin Neurosci*. Oct 2019; 68(): 101-104. PubMed

59. Lerner ZF, Gasparri GM, Bair MO, et al. An untethered ankle exoskeleton improves walking economy in a pilot study of individuals with cerebral palsy. *IEEE Trans Neural Syst Rehabil Eng*. 2018 10;26(10):1985-1993. PubMed

60. Matsuda M, Iwasaki N, Mataki Y, et al. Robot-assisted training using Hybrid Assistive Limb R for cerebral palsy. *Brain Dev*. 2018; 40(8): 642-648. PubMed

61. Matsuda M, Mataki Y, Mutsuzaki H, et al. Immediate effects of a single session of robot-assisted gait training using Hybrid Assistive Limb (HAL) for cerebral palsy. *J Phys Ther Sci.* 2018; 30(2): 207-212. PubMed

62. Takahashi K, Mutsuzaki H, Mataki Y, et al. Safety and immediate effect of gait training using a Hybrid Assistive Limb in patients with cerebral palsy. *J Phys Ther Sci*. 2018; 30(8): 1009-1013. PubMed

63. Lerner ZF, Damiano DL, Bulea TC. The Effects of Exoskeleton Assisted Knee Extension on Lower-Extremity Gait Kinematics, Kinetics, and Muscle Activity in Children with Cerebral Palsy. *Sci*. 2017 10 18;7(1):13512. PubMed

64. van Hedel HJ, Meyer-Heim A, Rusch-Bohtz C. Robot-assisted gait training might be beneficial for more severely affected children with cerebral palsy. *Dev Neurorehabil*. 2016; 19(6): 410-415. PubMed

Single-Arm Studies and Alternative Intervention – RAGT With Physical Therapy

65. Beretta E, Storm FA, Strazzer S, et al. effect of robot-assisted gait training in a large population of children with motor impairment due to cerebral palsy or acquired brain injury. *Arch Phys Med Rehabil*. 2020; 101(1): 106-112. PubMed

Single-Arm Studies and Alternative Intervention — Robotic Resistance Training

66. Conner BC, Schwartz MH, Lerner ZF. Pilot evaluation of changes in motor control after wearable robotic resistance training in children with cerebral palsy. *J Biomech.* 2021;126:110601. PubMed

67. Conner BC, Remec NM, Orum EK, Frank EM, Lerner ZF. Wearable adaptive resistance training improves ankle strength, walking efficiency and mobility in cerebral palsy: a pilot clinical trial. *IEEE Open J Eng Med Biol.* 2020;1:282-289. PubMed

Single-Arm Studies and Unclear Intervention

68. Lerner ZF, Damiano DL, Bulea TC. A lower-extremity exoskeleton improves knee extension in children with crouch gait from cerebral palsy. *Sci Transl Med*. 2017; 9(404): 23. PubMed

69. Wu M, Kim J, Arora P, Gaebler-Spira DJ, Zhang Y. Kinematic and EMG responses to pelvis and leg assistance force during treadmill walking in children with cerebral palsy. *Neural Plast*. 2016;2016:5020348. PubMed

Review Articles

Meta-Analyses — Unclear if Based on Systematic Review

70. Olmos-Gomez R, Gomez-Conesa A, Calvo-Munoz I, Lopez-Lopez JA. Effects of robotic-assisted gait training in children and adolescents with cerebral palsy: a network meta-analysis. *J Clin Med*. 2021; 10(21): 24. PubMed

Additional References

Conference Abstracts or Proceedings

71. Cherni Y, Ballaz L, Girarin-Vignola G, Begon M. P 175 - Robotic-assisted locomotion training improves walking abilities in children with bilateral cerebral palsy [conference abstract]. *Gait Posture*. 2018; 65: 530-531.

72. Kerr L. Robotic-assisted backward gait result in functional mobility changes in two children diagnosed with cerebral palsy [conference abstract]. *Arch Phys Med Rehabil*. 2017;98(10):e106-e106.
The purpose is to investigate the utilization of robotic-assisted backward walking to provide high-level repetitions in task specific practice for 2 children diagnosed with cerebral palsy (CP). Would this training program of intensive and repetitive backward walking result in positive functional mobility changes in children with CP?

73. Peri E, Biffi E, Maghini C, et al. An ecological evaluation of the metabolic benefits due to robot-assisted gait training. *Annu Int Conf IEEE Eng Med Biol Soc*. Aug 2015; 2015: 3590-3. PubMed