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Systematic Review of EMG-Driven Robots in Lower Extremity Post-Stroke Rehabilitation

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Systematyczny przegląd piśmiennictwa dotyczący wykorzystania robotów EMG w rehabilitacji kończyny dolnej u osób po udarze mózgu

Streszczenie

Udar mózgu jest powszechnym problemem zdrowotnym na całym świecie, często powodującym deficyty kończyn dolnych i stanowiącym znaczne wyzwanie dla fizjoterapeutów w zakresie rehabilitacji chodu. Wraz z postępem technologicznym, opracowano nowe narzędzia rehabilitacyjne, takie jak roboty sterowane za pomocą elektromiografii (EMG). Jednakże, ze względu na ich wysoki koszt, konieczne jest zbadanie ich skuteczności w rehabilitacji. W związku z tym celem tej pracy było określenie skuteczności terapii z wykorzystaniem robotów sterowanych EMG w porów-

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naniu do konwencjonalnej fizjoterapii w rehabilitacji chodu u pacjentów po udarze mózgu. Korzystając z baz danych PubMed, Cochrane i PEDro przeprowadzono systematyczny przegląd literatury. Do przeglądu włączono randomizowane badania kliniczne (RCT), skupiające się na pacjentach po udarze mózgu z zaburzeniami chodu, w których do jego oceny wykorzystano kliniczne skale funkcjonalne. Do przeglądu włączono 3 badania, które nie wykazały istotnej poprawy w zakresie lokomocji, wyników funkcjonalnych ani parametrów równowagi wyłącznie przy użyciu robotów sterowanych EMG. Jednakże, gdy były one stosowane w połączeniu z konwencjonalną fizjoterapią, zaobserwowano poprawę tych wyników. Stwierdzono pozytywne efekty w zakresie spastyczności i obwodu uda. Podsumowując, roboty sterowane EMG mogą być skutecznym sposobem poprawy rehabilitacji chodu u pacjentów po udarze mózgu, konieczne jest jednak przeprowadzenie dalszych badań z określonym protokołem i wyjaśnieniem dostosowania do każdego pacjenta.

Słowa kluczowe: udar mózgu, hemipareza, sterowanie EMG, interwencja robotyczna, rehabilitacja chodu.

Abstract

Stroke is a prevalent health issue worldwide, often leading to lower extremity deficits and posing a significant challenge for physiotherapists in terms of gait rehabilitation. With the advent of technological advancements, new rehabilitation tools like EMG-driven robots have been developed. However, their effectiveness in rehabilitation needs to be explored due to their high cost. Therefore, this study aimed to determine whether EMG-driven robot therapy was more effective than conventional physiotherapy for gait rehabilitation in stroke patients. The researchers conducted a literature search using the PubMed, Cochrane, and PEDro databases and included only randomized controlled trials (RCTs) focused on stroke patients with gait impairment, assessed using clinical functional scales. The treatment compared EMG-driven robot therapy for the lower extremities with conventional therapy. The analysis included three studies, which showed no significant improvement in locomotion, functional outcomes, or balance parameters with EMG-driven robots alone. However, when combined with conventional physiotherapy, EMG-driven robots demonstrated improvement in these outcomes. Positive effects were observed for spasticity and thigh circumference. In conclusion, EMG-driven robots can be an effective way to improve gait rehabilitation in stroke patients; however, further research with a specific protocol and explanation of the adaptation to each patient is needed.

Keywords: Stroke; Hemiparesis; EMG-triggered; robot intervention; gait rehabilitation.

Introduction

With a growing size and aging population, stroke is a worldwide health problem and one of the leading causes of disability in adults, counting every year 12–15 million people (GBD 2019 Stroke Collaborators, 2021). Depending on whether the stroke is an ischemic or hemorrhagic stroke, the cause is, respectively, narrowing or complete blocking of the blood vessels, reducing blood and nutrient supply to the brain, leading to brain cell death, or a leak/rupture of a blood vessel leading to a hemorrhage. Hemiparesis is one of the main consequences of cerebrovascular accidents, resulting in lower limb impairment and gait performance deficits (Kooncumchoo et al., 2021). In fact, only 30% of stroke survivors are able to walk independently (Kiper et al., 2020; Luque-Moreno et al., 2021). Therefore, gait rehabilitation is a major issue for physiotherapists in this type of patient (Louie et al., 2020; Luque-Moreno et al., 2016).

In recent years, a new form of neurorehabilitation, specific to stroke patients' gait cycle improvement, has been increasingly used in therapeutic management: electromyography-driven robotic training (Lewandowska-Sroka et al., 2021). This falls under the category of exoskeletons defined by Gorgey et al. (2019) as wearable robotic units aimed at restoring locomotion (Gorgey et al., 2019). This specific type of robot captures the EMG signal of the muscles and thus helps the patient perform a movement. Due to the active participation of the individual, the sensorimotor network shows significantly higher activation than if the movement is performed passively, which allows learning how to use these preserved paths (Kiper et al., 2016; Lewandowska-Sroka et al., 2021). EMG-driven robots can differ in the way the signal is recorded; some of them use superficial EMG signals with non-invasive electrodes while others use needles and fine wires, which can record deeper muscle signals (Chowdhury et al., 2013). Some examples of EMG-driven exoskeletons used for the rehabilitation of stroke are the Hybrid Assistive Limb (HAL) and the LUNA EMG robot (Nakajima et al., 2021; Oleksy et al., 2022). Physiotherapists may wonder if these new expensive devices could be efficiently implemented for the rehabilitation of this major public health problem and if their effectiveness would be worth their financial cost.

Therefore, the aim of this review was to investigate the current literature on the effectiveness of EMG-driven robots for gait management in the physiotherapy treatment of stroke patients. The research question was: "In adult post-stroke hemiparetic patients, what is the effect of EMG-driven robots on gait rehabilitation compared to conventional physiotherapy training (CPT)?"

Methods

A systematic literature search was conducted in February 2022 using three databases: PubMed, Cochrane trials, and PEDro. Study selection was performed following the PRISMA guidelines (Page et al., 2021) and is summarized in the PRISMA flow diagram presented in Figure 1. We formulated the terms for Population, Intervention, Comparison, Outcomes, and study design (PICOs) framework as follows:

— Population: Stroke patients;
— Intervention: EMG-robot, Exoskeleton;
— Comparison: Conventional physiotherapy rehabilitation;

— Outcomes: 6-Minute Walking Test (6MWT), Functional Ambulatory Categories (FAC), Time-up and Go (TUG) test and the Berg Balance Scale (BBS);
— Study design: Randomized Controlled Trial (RCT).

Boolean operators and key terms were used to build search strategies. The ways in which the key terms were associated to form the search strategies are presented in Table A1. The search was limited to peer-reviewed articles published in English and involving human subjects. No restrictions regarding publication dates were applied. Two reviewers conducted the search, and any disagreements were resolved by a third one.

Studies were included based on the following inclusion criteria: all post-stroke patients were accepted, regardless of the stage or type of stroke; EMG-driven robot for a lower limb must be the intervention; the intervention needs to be compared to CPT and at least one of the selected (6 MWT, TUG, BBS, and FAC) outcomes were present (Alghadir et al., 2018; Flansbjer et al., 2005; Mehrholz et al., 2007). Studies were excluded if they included patients with traumatic brain injury or spinal cord injury and if the robot was used for the upper limb.

Using version 2 of the Cochrane risk of bias tool for randomized trials (RoB 2), two independent reviewers assessed the quality of the studies included in the analysis (Sterne et al., 2019). The risk of bias assessment encompassed five criteria, which were: random sequence generation and allocation concealment (randomization bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and overall bias.

Results

Out of 379 identified records, 22 were deemed eligible for screening and ultimately, 3 were included in the review (Figure 1). Two studies evaluated the effectiveness of the HAL robot device (Sczesny-Kaiser et al., 2019; Wall et al., 2020), while another study investigated the use of the LUNA EMG robot as a rehabilitation device (Lewandowska-Sroka et al., 2021). Table 1 illustrates the characteristics of the included studies.

Both studies which evaluated the use of the HAL robot found no significant differences between the intervention and control groups for any of the measured outcomes (Sczesny-Kaiser et al., 2019; Wall et al., 2020). In the study conducted by Lewandowska-Sroka et al. (2021), Bayesian statistics were used to compare LUNA EMG robot and control exercises (Lewandowska-Sroka et al., 2021). The EMG-driven robotic training group had a significantly higher reduction in spasticity of the knee flexors and extensors. Another main difference observed was in thigh circumference measurements, where there was a credible increase with LUNA EMG robot training (Lewandowska-Sroka et al., 2021). Although both groups showed improvement in their TUG scores, there was no significant difference between them.

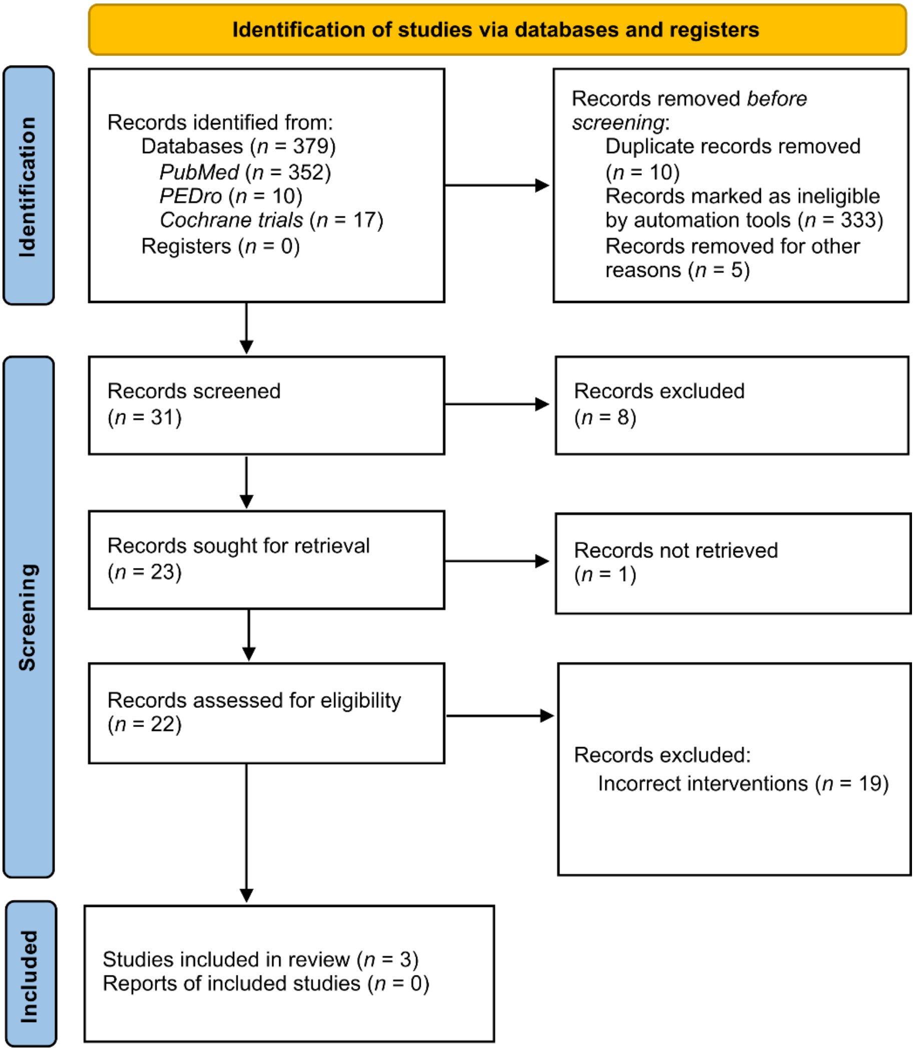

Figure 1
PRISMA flow diagram

Table 1
Characteristics of the included studies

Article	**Sczesny-Kaiser et al. (2019)**	**Wall et al. (2020)**	**Lewandowska-Sroka et al. (2021)**
Partici-pants	Description: Ambulatory, chronic stroke patients with incomplete hemiparesis after a single incident of an ischemic or a hemorrhagic stroke Number of participants/studies: 18 Sampling procedure: Randomly assigned to Group 1 and Group 2 using a computer-generated list Age: 18 to 75 years old Gender: Male and Female	Description: Subacute stroke patients with an inability to walk or in need of continuous manual support to walk due to legs paresis Number of participants/studies: 33 Sampling procedure: A nurse, not otherwise involved in the study, manually randomized the patients according to a block design to either incorporated HAL training or CGT only Age: 51 (Mean age) Gender: Male and Female	Description: Patients with an impaired motor function and gait after an ischemic subacute stroke Number of participants: 60 Sampling procedure: All the participants evenly distributed regarding their gender or age and no obvious similarities between groups noticed Age: 66.8 (Mean age) Gender: Male and Female
Drop-out	No drop-out but patient number 10 missed 2 sessions of conventional PT because of logistic trouble resulting in 28 sessions.	2 patients were lost to follow up (at T3), both in the CONV group, due to private or medical factors.	11 patients have been disqualified during study (3- absenteeism over 10% of training, 5- shorter than 4 weeks, 3-another stroke episode during the research)
Interven-tions	Intervention duration: 6 weeks	Intervention duration: 4 weeks	Intervention duration: 6 weeks
Name-Treatment Category	Follow-up: at baseline, at crossover and at the end of the study. HAL-BWSTT (intervention) group: Exoskeleton 30-min individual training sessions, 5X/we CPT (control) group – Mixed intervention with Bobath's concept, PNF, motor (re)learning programs 30-45-min individual training sessions, 5X/we	Follow-up: at baseline, after the intervention and 6 months after stroke HAL (intervention) group – Gait training with HAL 90-min training session, 4X/we CGT (control) group – Training of motor function in the upper and lower extremity, trunk control, transferring oneself and gait 30-60min training sessions, 5 X/we	Follow-up: at baseline, at weeks 2, 4 and 6. Robot (intervention) group – Individual standard physiotherapy (kinesiotherapy, physical therapy, classical lower limb massage) and rehabilitation with robot Luna EMG 90-120-min training session, 5X/we Control group – Individual standard physiotherapy (kinesiotherapy, physical therapy, classical lower limb massage) + use of a lower limb rotor 90–120-min training session, 5X/we
Outcomes Measures	Primary outcome: Walking time (10MWT), Time (TUG), Distance (6MWT) Secondary outcome: FAC, BBS	Primary outcome: FAC Secondary outcome: Fugl-Meyer Assessment, 2MWT, BBS, BI	Primary outcome: TUG, Ashworth scale, Tight circumference, Lovett scale assessment, ROM
Results	Walking, functional and balance metrics → No difference between both groups	Walking, movement function, self-selected walking speed, balance, self-care → No significant difference	↑ in both groups Better ↑ spasticity + thigh circumference: Robotic group

Abbreviations*:* Hybrid Assistive Limb (HAL); Conventional Physiotherapy (CPT); Body-weight supported treadmill training (BWSTT); 10-Minute Walking Test (10MWT), 6-Minute Walking Test (6MWT), Functional Ambulatory Categories (FAC); Berg-Balance Scale (BBS); Conventional Gait Training (CGT); 2-Minute Walking Test (2MWT); Range of Motion (ROM); ↑= improvement

Figure 2 illustrates the results of the risk of bias assessment. Of the included studies, two were classified as having an overall bias of *'some concerns'*, while one was classified as having *'high'* bias. Two studies had '*some concerns'* regarding allocation concealment, as the concealment method was either not described or lacked sufficient detail for judgment. Additionally, two studies had '*some concerns*' about deviation from the intended intervention, while one study had a '*high'* risk of bias due to missing outcome data.

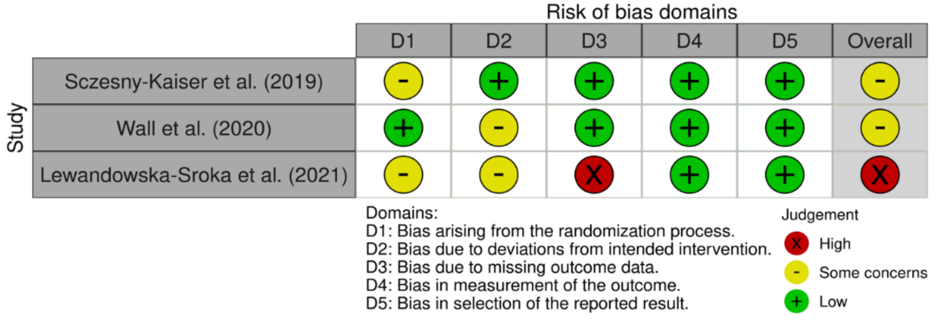

Figure 2
Risk of bias assessment results

Discussion

Summary of evidence

The aim of the systematic review was to determine whether EMG-driven robot therapy is more effective than conventional physiotherapy. Finally, only three articles were included in this publication. Each of them was randomized, in which a total of 111 patients were studied. The treatment duration was 4 to 6 weeks. A follow-up study was made after each intervention. In two of the three studies, HAL training was incorporated as part of the rehabilitation program. In one study LUNA EMG robotic device was used as an intervention tool. In the control groups rehabilitation was based on mixed intervention with Bobath's concept, PNF, motor (re)learning programs, training of motor function in the upper and lower extremity, trunk control, transferring oneself and gait, standard physiotherapy and lower limb rotor exercises. Two of the three studies revealed no significant difference between groups in walking tests (10MWT, 6MWT, 2MWT). There was no significant difference between groups in the functional correlate to balance and fall risk metrics either. In the study about using EMG-triggered therapy in rehabilitation of stroke patients, both proposed rehabilitation protocols significantly improved the patients' condition regarding all measured outcomes, but the spasticity and thigh circumference improved significantly better in the robotic group in comparison to controls.

Overall, the HAL training was not found to be significantly more effective than mixed-approach CPT for improving walking, functional and balance metrics in ambulatory, chronic stroke patients (Sczesny-Kaiser et al., 2019). For subacute stroke patients, no significant effect of HAL training was found when compared with CGT for improving lower limb function (Wall et al., 2020). As for the other type of EMG-driven robot, LUNA EMG, which was used in combination with standard physiotherapy, was found to be superior to standard physiotherapy alone for improving gait function. However, it was better than standard physiotherapy alone for reducing spasticity and increasing thigh circumference, which are two parameters that can influence gait (Lewandowska-Sroka et al., 2021).

All three studies used EMG-driven robots, where sEMG surface was used to detect the electromyography signals. In these studies, two out of three showed that the effectiveness of EMG-driven robot rehabilitation alone in improving lower limb function in stroke patients is questionable due to the lack of significant results. Poor quality of life is a major cause of stroke; therefore, we can assume that these patients are likely to carry a more significant quantity of subcutaneous tissue and thus alter the signals retrieved, which could explain the results. We cannot neglect the fact that the use of sEMG may not be the most reliable for this type of patient (Kiper et al., 2021). In fact, sEMG highly depends on the depth of subcutaneous tissue; the more fat the patient has, the less accurate the signal is (Türker, 1993). Moreover, this type of EMG also requires very good contact with the skin to work optimally, contrary to intramuscular EMG. They are also known to have difficulty in targeting a specific muscle, especially when it is not superficial (Türker, 1993).

It would be interesting to conduct further investigations on this subject regarding the exponential number of stroke survivors. These new technologies may have a greater impact on a certain type of stroke, at a certain stage, or on younger patients who may be more responsive. It is possible that an alternative method for retrieving EMG signals is more reliable. Because these new technologies are expensive, it is necessary to evaluate the effectiveness of EMG-driven robots for stroke patients to determine whether they can be used for a larger number of stroke patients.

Limitation of the included studies

Some limitations were found at the level of the studies. First, the design of Sczesny-Kaiser et al. (2019) study can be considered a limitation because it is a crossover design where a “washout” period is present. In this case, statistical analysis was performed to ensure no carryover effects. However, there is no certainty regarding the possibility of maintaining the newly acquired motor skills, which could be an advantage for the second treatment phase of the crossover (Sczesny-Kaiser et al., 2019). Moreover, the crossover trials took more time, and if the participants did not complete all stages of the trial, the statistical analysis may be complicated (Wellek & Blettner, 2012).

Thus, having a small sample size decreased the statistical power of Sczesny-Kaiser et al. (2019) and Wall et al. (2020) articles results. In addition, the sample of Wall et al. (2020) study was not representative of the population because it was composed of a majority of men while stroke appears more frequently in en elderly population, especially in women (Ovbiagele & Nguyen-Huynh, 2011). Another major limitation in Wall et al. (2020) study was the difference in duration and session repetition per week between the HAL and CGT groups. Dropouts were reported in Wall et al. (2020) and Lewandowska-Sroka et al. (2021) studies; therefore, it decreased the statistical power of the studies.

At the level of review limitations, the fact that articles only in English could have led to missing interesting articles on this subject should be taken into account. In addition, there is a possibility that our search strategy could have also missed some articles; however, it was made to cover the maximum amount of literature possible about this topic. In addition, as all types and stages of stroke were included in this review, it was difficult to compare the results. Another limitation is the small number of articles included. Finally, the heterogeneity of the protocols and EMG-driven robots in the three studies make it difficult to compare the results obtained.

Conclusion

In summary, no relevant conclusion can be drawn about the effectiveness of EMG-driven robots alone for post-stroke patients' gait in comparison with conventional physiotherapy training, but it seems that a mixed approach combining both of them could be the most beneficial. However, the results of these studies need to be interpreted with caution as the sample sizes and participants enrolled may not be able to reflect their results to the entire population. Further studies should be conducted with larger sample sizes and more heterogeneous participants to increase the power of the study. Therefore, there is a need to conduct more studies like RCTs to evaluate the effectiveness of EMG-driven robots for lower limb rehabilitation in patients with different stages of stroke and with different types of EMG-driven robots. The next studies should focus on standardizing testing protocols so that we can understand how much therapy is needed to improve a patient's functional condition.

Appendix

Table A1
Database search strategies on Cochrane, PubMed and PEDro

Research steps	Type of search terms	Results
Cohrane		
#1	MeSH descriptor: [Exoskeleton Device] explode all trees	48
#2	(EMG-driven robot): ti, ab, kw	11
#3	#1 OR #2	58
#4	(stroke): ti, ab, kw	61,269
#5	(„cerebrovascular accident"): ti, ab, kw	13,946
#6	#4 OR #5	64,027
#7	(gait): ti, ab, kw	11,006
#8	(lower limb): ti, ab, kw	13,569
#9	(walk): ti, ab, kw	34,342
#10	#7 OR #8 OR #9	49,975
#11	#3 AND #6 AND #10	17
PubMed		
1	(EMG robot* OR exoskeleton OR machine)	152,205
2	(stroke OR cerebrovascular accident)	395,097
3	(walk* OR gait)	263,170
4	(EMG robot* OR exoskeleton OR machine) AND (stroke OR cerebrovascular accident) AND (walk* OR gait)	352
PEDro		
1	Exoskeleton AND stroke AND walking	10

Abbreviations: ti, ab, kw: Searches the Title field, Abstract field, Keyword field

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interests with respect to the research, authorship, and/or publication of the article *Systematic Review of EMG-Driven Robots in Lower Extremity Post-Stroke Rehabilitation.*

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