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Robotic-assisted range of motion therapy on limb muscle tone in chronic stroke patients: A systematic review

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Abstract

Background: Stroke is a sudden neurological deficit that arises from vascular damage in the central nervous system, which can lead to disabilities, particularly affecting the movement capabilities of those impacted. While often associated with older adults, the occurrence of stroke in younger individuals has risen in recent years. The disabilities that result from strokes in younger adults can contribute to economic challenges and a reduced quality of life. To mitigate the functional limitations caused by stroke, interventions such as Robotic Range of Motion (ROM) can be utilized, taking advantage of technological advancements. Robotic ROM techniques can improve muscle tone in the limbs, and it is anticipated that consistent ROM interventions will effectively alleviate movement restrictions in these areas.
Purpose: To identify robotic-assisted range of motion therapy on limb muscle tone in chronic stroke patients.
Method: A systematic review approach in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles were sourced from online databases such as PubMed, Google Scholar, and ProQuest. The review was organized according to the PICOS framework. In this article, the PICOS criteria were defined as follows: P: Stroke patients, I: Range of Motion (ROM) exercises using robotics, C: Inclusion of a control group, O: Improvement in muscle tone, S: Randomized Controlled Trial (RCT). The keywords used in the search included "range of motion," "robotic intervention," "muscular tone," and "stroke patient." Articles were selected based on specific inclusion criteria: publication within the last five years (2019-2024), English language, use of robotics in interventions, focus on stroke patients, application of randomized controlled trial research methods, and availability of the full text.
Results: The literature review of the five journals revealed that Robotic ROM interventions are effective in enhancing muscle tone in stroke patients. This conclusion is backed by clinical evidence gathered from the analysis of these journals.
Conclusion: Based on the analysis of the five articles, it is evident that ROM intervention utilizing robotics through various methods positively affects the extremities of stroke patients.

Keyword: Muscular Tone; Range of Motion; Robotic Intervention; Stroke Patient.

INTRODUCTION

Stroke is the second leading cause of death and disability globally. It is characterized by acute and focal neurological deficits resulting from vascular injury to the central nervous system. Stroke is not a single disease but can be triggered by various risk factors, processes, and disease mechanisms (Paolucci, Agostini, Mangone, Bernetti, Pezzi, Liotti, & Saggini, 2021). It also leads to significant morbidity

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and disability among survivors, with neurological impairments profoundly affecting patients' lives (Aprile, Guardati, Cipolini, Papadopoulou, Mastrosa, Casteli, & Germanotta, 2020).

Stroke rehabilitation aims to improve the individuals' quality of life through the alleviation and treatment of these impairments. Neurological rehabilitation for stroke involves physical agents, exercise therapy, and orthoses. Recently, robotic rehabilitation systems have been developed and made available to patients (Adomavičienė, Daunoravičienė, Kubilius, Varžaitytė, & Raistenskis, 2019). These robotic systems offer advantages over traditional rehabilitation methods, such as providing repetitive, high-intensity training with less reliance on therapists. They also typically offer visual or auditory feedback to keep patients motivated and ensure they perform tasks correctly. Research has shown that sensorimotor training using robotic systems can improve upper extremity functions (Lodha, Patel, Casamento, Hays, Poisson, & Christou, 2019).

While strokes predominantly affect the elderly, with less than 5% occurring in younger individuals, the incidence of stroke among young adults has been rising in recent decades. Disabilities from stroke in young adults can lead to economic challenges and a decreased quality of life (Mahendrakrisna, Windriya, & GTS, 2019). Annually, 15 million people are newly affected by stroke, with about a third, approximately 6.6 million, resulting in death. A common issue among stroke patients is a reduced quality of life due to impaired mobility. Those who struggle with walking often suffer from muscle weakness and balance disorders (immobilization) (Agusrianto & Rantesigi, 2020). Stroke patients with disabilities often require support from family, friends, and healthcare providers. This support is crucial, as stroke not only affects physical mobility and daily activities but also impairs psychosocial abilities, leading to challenges in social interaction (Tunik, 2023).

Robotic rehabilitation systems for the upper extremities encompass a variety of devices. Some of these systems utilize servomotors to administer repetitive and passive movements to the upper limbs, which can occur in 2D or 3D planes and are typically tracked via a monitor (Kager, Hussain, Cherpin, Melendez, Takagi, Endo, & Campolo, 2019). More advanced devices, such as exoskeletons, offer multidirectional and multiplanar movements, and they often detect and facilitate voluntary movements (Cherpin, Kager, Budhota, Contu, Vishwanath, Kuah, & Campolo, 2019). The ability to detect voluntary movements allows patients to engage in biofeedback training, which helps motivate them as they achieve their goals. Research on robot-assisted therapy is expanding rapidly, with most studies indicating that these systems are either comparable to or superior to conventional methods in achieving primary outcomes (Iwamoto, Imura, Suzukawa, Fukuyama, Ishii, Taki, & Araki, 2019).

Despite the growing evidence supporting the effectiveness of robot-assisted therapy, there are concerns about its practical application (Rodgers, Bosomworth, Krebs, Van Wijck, Howel, Wilson, & Shaw, 2019). Challenges include the lack of a standardized protocol and variations in the devices used. The heterogeneity of studies complicates conclusions regarding the effectiveness and the time and intensity needed for improvement. While many studies report enhanced upper extremity functions, most do not address or fail to demonstrate improvements in daily life activities or fine motor movements of the hand (Coscia, Wessel, Chaudry, Millan, Micera, Guggisberg, & Hummel, 2019).

Although the effects of various robotic rehabilitation systems on stroke patients' motor functions are well documented, these patients also face cognitive and emotional challenges. As technology advances, robotic rehabilitation systems are incorporating features like visual or auditory feedback, simple games, or motivational visual effects. These features can motivate patients to continue with tasks, improve their performance, and foster a sense of accomplishment, rather than just performing aimless movements. This sense of achievement can positively impact their emotional state, easing concerns about their condition worsening (Mehrholz, Pollock, Pohl, Kugler, & Elsner, 2020).

Robotic therapy has been proposed as an effective approach for rehabilitating stroke patients with mobility impairments. It aims to increase the quantity and intensity of therapy by providing complex yet controlled multisensory stimulation (Liu, Song, Li, Guan, & Ji, 2020). Additionally, robotic devices, equipped with sensors and actuators, can offer quantitative feedback on user agility. Currently, the use of robotic rehabilitation is recommended for

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addressing movement-related issues in stroke patients (Aprile, Germanotta, Cruciani, Loreti, Pecchioli, Cecchi, & Carroza, 2020).

RESEARCH METHOD

A systematic review with article selection guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The systematic review process begins with the formulation of clinical questions relevant to the topic. Before this, the authors establish PICOS criteria, which stand for: P (problem, patient, or population), I (intervention, prognostic factor, or exposure), C (comparison or control), O (outcome), and S (study design). For this article, the PICOS criteria are defined as follows: P: Stroke patients, I: Range of Motion (ROM) exercises using robotics, C: Presence of a control group, O: Improvement in muscle tone, S: Randomized Controlled Trial (RCT).

The article search was conducted systematically using the keywords: "Range of Motion" AND "Robotic Intervention" AND "Muscular Tone" AND "Stroke Patient." The search spanned three databases: PubMed, Google Scholar, and ProQuest. The search process was guided by predefined inclusion and exclusion criteria. The inclusion criteria required articles published within the last five years (2019-2024), written in English, involving robotic interventions for stroke patients, employing a randomized controlled trial (RCT) methodology, and with full-text availability. The exclusion criteria ruled out articles published before 2018, those not in English, irrelevant to stroke patient interventions, review articles, and studies not using RCT methodology.

The initial search resulted in 14 articles from PubMed, 1,840 from Google Scholar, and 301 from ProQuest, totalling 2,155 articles. After screening and filtering based on the predefined criteria, 5 articles met the inclusion criteria and were selected for further analysis. These articles were then assessed for quality using a 13-item questionnaire related to RCT design methodology.

RESEARCH RESULTS

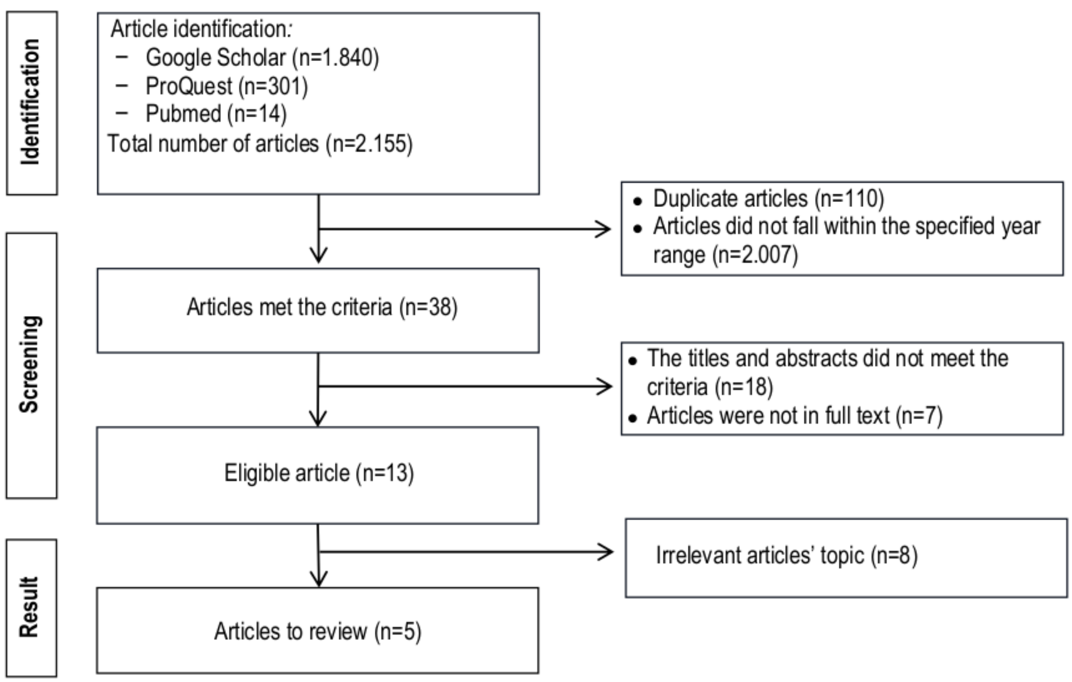

Figure 1: PRISMA Flow Diagram

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Table 1. The Main Characteristics of Included Studies

Author (Year) (Country)	Purpose	Method	Results
(Dehem, Giliaux, Stoguart, Detembleur, acquemin, Palumbo, & Lejeune, 2019) (Belgium)	To evaluate the effectiveness of upper-limb robotic-assisted therapy (RAT) used as partial substitution to conventional therapy in the early phase of stroke rehabilitation, following the 3 ICF domains	A randomized controlled trial design. Forty-five patients with acute stroke were randomly assigned to two groups: conventional therapy (n = 22) and robotic-assisted therapy (RAT) (n = 23). Both groups received interventions of equal duration over 9 weeks. The conventional therapy group underwent standard rehabilitation, while in the RAT group, four sessions of conventional therapy (25%) were replaced each week with RAT. The RAT involved moving the affected upper limb along a reference trajectory, with the robot providing assistance as needed. A blinded assessor evaluated the participants before the intervention, immediately after, and six months post-stroke, focusing on ICF domains such as upper limb motor impairments, activity limitations, and social participation restrictions.	In total, 28 individuals were assessed after the intervention. The following were more improved in the RAT than conventional therapy group at 6 months post-stroke: gross manual dexterity (Box and Block test +7.7 blocks; P = 0.02), upper-limb ability during functional tasks (Wolf Motor Function test +12%; P = 0.02) and patient social participation (Stroke Impact Scale +18%; P = 0.01). Participants' abilities to perform manual activities and activities of daily living improved similarly in both groups.
(Taravati, Capaci, Uzumcugil, & Tanigor, 2022) (Italy)	To find out whether including robotic therapy in addition to a conventional rehabilitation program affects the quality of life, motor function, cognition, and emotional status of hemiplegic patients.	A randomized controlled trial design. Thirty-seven stroke patients recruited between April 2016 and April 2019 were included in the study. The patients were randomized into 2 groups (Robotic rehabilitation group-RR n:17, control group n:20), RR was arranged to be 30–45 min, 5 days per week for 4 weeks. All patients were assessed at the beginning of therapy and the end of 4th week with Brunnstrom stages of motor recovery, Fugl-Meyer Assessment (FMA), handgrip strength, Purdue peg test, Minnesota Manual dexterity test, Modifed Ashworth Scale (MAS), Functional Independence Measure (FIM), Stroke Specifc Quality of Life Scale (SS-QOL), Nottingham Extended Activities of Daily Living (NEADL) Scale, Montreal Cognitive Assessment (MoCA) and Center for Epidemiological Studies Depression Scale (CES- D).	The robotic group showed greater improvements in motor function scores, spasticity, overall functioning, activities of daily living, and cognitive assessments compared to the control group, but this difference was not statistically significant (p>0.05). Improvement in the CES-D in the RR-group was better in comparison to the control group (p=0.018).

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Author (Year) (Country)	Purpose	Method	Results
(Wall, Borg, Vreede, & Palmcranzt, 2020) (Sweden)	To explore effects of incorporating gait training with Hybrid Assistive Limb (HAL) as part of an inpatient rehabilitation program after stroke.	A randomized controlled trial design. This prospective, randomized, open labeled, blinded evaluation (PROBE) study was conducted at the University Department of Rehabilitation Medicine at Danderyd Hospital, Stockholm, Sweden, admitting patients aged 18–67 years with moderate to severe acquired brain injury. The recruitment period lasted between February 2014 and December 2016, with the last follow-up performed in May 2017. All participants in this study expressed informed consent	No differences were observed between the groups in any outcomes after the intervention or at 6 months' post-stroke, despite the additional resources required for Hybrid Assistive Limb (HAL) training. Among these younger patients with hemiparesis and severe walking limitations during the subacute stage, walking independence at 6 months was linked more to younger age than to group assignment. These results should be interpreted with caution due to the small sample size, smaller than expected differences between groups, and greater than expected variance. The findings indicate that future studies should further investigate which individuals within the diverse stroke population are most likely to benefit from Exoskeleton-Assisted Gait Training (EAGT).
(Cho, Lee, Shin, & Kim, 2021) (Korea)	To examine the impact of a bi-axial ankle muscle training program using visual feedback on enhancing ankle strength and functional activity performance in stroke patients.	A randomized controlled pilot trial with concealed allocation and assessor blinding and intention-to-treat analysis. Twenty-five stroke patients with walking difficulties, such as foot drop or ankle muscle weakness, who were undergoing inpatient rehabilitation were included in the study. The experimental group participated in ankle muscle training, which involved passive stretching, ankle muscle control, and active-resistive strengthening with visual feedback, for 40 minutes per day, 5 times a week for 4 weeks. The control group received ankle-focused physical therapy, including ankle range-of-motion exercises. Both groups had the same amount of training time. The outcomes measured included	The analysis showed significant differences between the groups in ankle muscle tone in all directions (P < 0.05), Fugl-Meyer score (P < 0.01), and stance-phase co-contraction index (P < 0.05). Following the training, the experimental group demonstrated significant improvements within the group in ankle muscle tone in all directions (P < 0.01), ankle proprioception (P < 0.05), and walking speed (P < 0.05).

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Author (Year) (Country)	Purpose	Method	Results
		isometric ankle contraction force to evaluate ankle muscle tone, ankle proprioception, Fugl-Meyer lower extremity score, Berg balance scale score, walking speed, and ankle co-contraction index to assess muscle efficiency during gait.	
(Budhota, Chua, Hussain, Kager, Cherpin, Contu, & Campolo, 2021) (Singapore)	To investigate how a time-matched combination of conventional therapy and robotic-assisted therapy (RAT) using the H-Man device compares with conventional training in terms of reducing workforce demands.	In a randomized controlled trial, forty-four stroke survivors in the subacute to chronic phase with their first-ever clinical stroke and primarily arm motor function deficits were recruited and randomly assigned to two groups of 22 subjects: Robotic Therapy (RT) and Conventional Therapy (CT). Both groups underwent 18 sessions, each lasting 90 minutes, with three sessions per week over 6 weeks. The CT group received 90 minutes of one-on-one therapist-supervised conventional therapy per session, while the RT group participated in combinatory training, consisting of 60 minutes of minimally supervised H-Man therapy followed by 30 minutes of conventional therapy. Clinical outcomes [Fugl-Meyer (FMA), Action Research Arm Test, and Grip Strength] and quantitative measures (smoothness, time efficiency, and task error from two robotic assessment tasks) were independently evaluated before the therapy intervention (week 0), at mid-training (week 3), at the end of training (week 6), and post-therapy (weeks 12 and 24).	Time matched combinatory robotic therapy that integrates robotic aided therapy and therapist supervised therapy in a 2:1 ratio, using H-Man, was safe, efficacious, and acceptable in a supervised manner. The stroke participants who underwent this combinatory training showed comparable improvements in motor function and higher performances in movement smoothness compared to stroke participants who underwent conventional therapy alone for the same duration. The motor and functional improvements were also retained following the therapy. This promotes the use of the present robotic therapy program for 18 weeks to improve stroke motor recovery and reduce therapists' workload which can lead to reduced human effort and enhanced productivity.

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DISCUSSION

The first article utilized a Randomized Control Trial (RCT) design with two groups, randomly selecting participants from three inpatient rehabilitation centers in Belgium. A total of 45 participants meeting the criteria were included, with 22 in the control group and 23 in the experimental group. Both groups received a 9-week intervention involving upper limb robotic-assisted therapy (RAT) using rehabilitation robots. The results indicated that combining robotic therapy with conventional therapy was more effective in improving dexterity than conventional therapy alone. The RAT group performed an average of 520 movements per 45-minute session. This study suggests that RAT may be more effective than conventional therapy in enhancing upper limb function (Dehem et al., 2019).

The second article also used an RCT design to compare the effects of robotic rehabilitation with conventional rehabilitation in stroke patients. It involved 45 patients, with 22 in the robotic rehabilitation group and 23 in the conventional rehabilitation group. The robotic group used the ReoGo™-Motorika device for upper limb rehabilitation, where patients moved their arms and hands to reach virtual targets on a screen. The robotic rehabilitation sessions lasted 30–45 minutes, 5 days a week, over 4 weeks. The Fugl-Meyer Assessment (FMA) showed that the robotic group's scores improved from an average of 33 to 41.59 (p=0.001), while the conventional therapy group's scores improved from 34 to 39.45 (p=0.001). These results demonstrate an improvement in motor function, with robotic therapy helping stroke patients practice arm movements that simulate daily life tasks (Taravati et al., 2022).

The third article employed an RCT design with two experimental groups—Hybrid Assistive Limb (HAL) and a control group (CGT). This study evaluated the effectiveness of using the electromechanical gait machine HAL for gait training in patients with walking difficulties. The study included 36 patients, with 18 in the control group and 18 in the experimental group. The intervention involved combining Gait Training with HAL as part of a post-stroke inpatient rehabilitation program, conducted 4 days a week for 4 weeks. The results showed no significant difference between the HAL group and the conventional group. However, both groups had positive outcomes, with the HAL group showing greater improvements in walking independence. Patients in the HAL group walked 500 meters farther than those in the CGT group and reported a much greater beneficial effect compared to CGT (p = 0.031) (Wall et al., 2020).

The fourth article employed a randomized controlled study design with two groups: one experimental group and one control group. After the selection process, the sample included 13 patients in the experimental group and 10 in the control group. The study focused on interventions for strengthening leg muscles using the AMT device. Participants in the experimental group were seated comfortably in an AMT chair and asked to face a monitor providing visual feedback. The intervention consisted of three stages: first, passive stretching to measure the maximum passive ROM of the ankle; second, training to control ankle muscle contractions by moving the foot passively from the original to the target position using a robotic device; and third, active-resistive strengthening, where participants actively moved their ankles to the target position without assistance. The AMT was conducted for 40 minutes per day, 5 times a week, over 4 weeks. The study found that AMT significantly increased ankle muscle tone and walking speed in stroke patients. Comparisons between the experimental and control groups showed similar results for ankle muscle tone (15.9 vs. 15.7, P=0.953) and balance (48.0 vs. 47.6, P=0.862), demonstrating that AMT effectively improves ankle muscle tone through repeated exercise (Cho et al., 2021).

The fifth study also used an RCT design with two groups. A total of 44 participants were divided equally into the RT (Robotic Therapy) group and the CT (Conventional Therapy) group. Both groups received 18 sessions, each lasting 90 minutes, conducted three times a week for 6 weeks. Participants in the RT group underwent a combination of robotic and conventional therapy, with 30 minutes dedicated to conventional therapy. In the RT group, participants sat in a chair with back support, with the H-Man robot positioned in front of them. A 32-inch flat-screen monitor provided visual feedback during the sessions. Visual stimuli in the software encouraged participants to move their extremities. Significant improvements were observed within the RT group across all clinical scales by the end of the training, compared to initial Fugl-Meyer Motor Assessment (FMA) scores: week 1

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RT: 40.23, CT: 35.86; week 6 RT: 44.64, CT: 38.86. Post-training FMA scores were RT: 45.33 and CT: 40.36, indicating the effectiveness of robotic therapy in enhancing motor function (Budhota et al., 2021).

CONCLUSION

Range of Motion (ROM) interventions using robotic devices, applied in various forms and methods, have a beneficial effect on the extremities of stroke patients, enhancing muscle tone. It is anticipated that robotic ROM interventions can expedite the healing process in stroke patients. Additionally, healthcare services in Indonesia should adopt ROM interventions for stroke patients to enhance their quality of life.

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