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Review

Effectiveness of Robotic Rehabilitation in the Management of Stroke Patients—A Literature Review

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ABSTRACT

Background and Objective: Stroke is considered a root cause of disability worldwide, adversely affecting movement and balance. It requires comprehensive rehabilitation to achieve maximum recovery. Gait training, including robot-assisted methods, is crucial in restoring independence among stroke survivors. Balance impairment leads to challenges that demand specialized interventions, while cognitive deficits add complexity to rehabilitation. Despite ongoing research, optimizing outcomes remains a challenge, urging innovation in trial design and intervention strategies to enhance the effectiveness during stroke rehabilitation. This literature review highlights the evidence regarding the uses and effectiveness of robotic rehabilitation amongst stroke survivors. **Methods:** The searches were performed on databases like PubMed, Scopus, and Google Scholar using keywords such as gait, balance, cognitive ability, and upper limb rehabilitation. The inclusion criteria were the studies published in English with a study design of randomized controlled trials focusing on stroke patients. The intervention included robotic rehabilitation. Qualitative data synthesis was gathered after screening the abstracts and full texts of the included articles. **Result:** This literature review found that robotic rehabilitation, including intensive and personalized sessions, targeted resistance, augmented feedback, and sensory inputs, yields significant improvements across multiple domains for stroke patients. These improvements include enhanced gait parameters, balance, cognitive abilities, and upper limb functionality. Robotic-assisted therapy can improve motor function, coordination, memory, attention, and sensory perception, ultimately contributing to better recovery and quality of life for individuals affected by stroke. **Conclusion:** This study concluded that combining robotic rehabilitation with other techniques can provide enhanced benefits compared to conventional rehabilitation. However, more studies are required to reach any firm conclusion.

Keywords—*Stroke, Gait, Robotic rehabilitation, Upper limb rehabilitation, Cognitive ability, Balance.*

INTRODUCTION

Stroke is the preliminary cause of disability observed amongst adults, leading to substantial financial consequences for victims, their families, and society as a whole. Following a stroke, disabilities are a hedge to healthcare and have several long-term counteraccusations on a person's capability to ambulate and maintain balance.[1] The unexpected reduction in brain conditioning causes weakness in one side of the lower extremities. Such individuals tend to depend more on the lower extremities, which are unaffected. They are more likely to have an inconsistent, unstable distribution of weight and a reduced gait cycle.[2] Thus, perfecting and recovering the capacity to walk is essential to gaining autonomy in day-to-day conditioning and perfecting daily life quality.[1] The general physical state and the strength, endurance, and coordination of their lower extremities amongst stroke survivors can be improved with gait training. Advancements in muscle tone normalization, balance, overall fitness and endurance, and functional skills are all included in the Barthel Index (BI) and Rivermead Mobility Index. These scales are accepted as suitable criteria to assess a stroke case's functional condition and are reliable labels of the effectiveness of the enforced therapy.[3]

Numerous strategies, including neurodevelopmental procedures, repeated task training, biofeedback, bodyweight-supported treadmill training, robot-supported training, and high-intensity physical therapy, have been used in neurorehabilitation programs to enhance balance and locomotor capabilities. Despite these initiatives, opinions on how well these approaches enhance balance and motor skills are still undiscovered.[1] One technique utilized to assist stroke victims in recovering their capacity to walk is robot-supported gait training. It enables the creation of walking movements continually, adding the number of gait cycles and step accuracy while requiring trainers to deliver the least amount of physical effort. An exoskeleton-assisted robot is generally used in robot-assisted gait training, which may be divided into two primary types: over-ground and treadmill-based exoskeleton robots.[4]

Amongst stroke victims, balance damage is a serious concern that can arise from several causes, including defined range of motion, muscular atrophy, sensitive abnormalities, and cognitive issues. This impairment makes movement delicate and raises the possibility of falling. The inability to integrate sensitive data from the vestibular, visual, and somatosensory systems is a major contributing factor. Balance is maintained by somatosensory signals from the lower extremities in healthy individuals, though stroke victims frequently do not receive this information. Balance requires central integration, which is the activation of substitute sensitive systems to make up for inadequacies. Balance capability can be enhanced using specialized training methods, like modifying sensory inputs or measuring balance with analytical equipment. However, studies on how stroke survivors' center of pressure movement and muscle activation are impacted by sensory integration.[5]

One of the most common physical impairments leading to stroke-related disability that affects the performance of daily living activities is gait disorder, which is a common clinical issue for stroke survivors. Therefore, a primary focus of post-stroke rehabilitation is gait disorder.[6]

Following a stroke, patients walk with coordinated lower extremities mass patterns instead of controlled movement of individual joints. Walking induces two kinds of synergistic patterns. While the hip, knee, and ankle dorsiflexors produce the mass flexion pattern during the swing phase, the quadriceps and gluteus maximus work in concert to produce a mass extension pattern during the stance phase. Basic deficits causing asymmetry include poor support for a single limb and uncontrollably moving forward. Reduced stance time and extended swing duration on the affected side make up the asymmetry. The gait cycle's regular pattern of symmetrical step length is absent, with the paretic side having a longer way.[7]

Post-stroke cognitive impairment is the term used to describe cognitive deficits that manifest three to six months following a stroke. The stroke itself can cause these deficits, or they can pre-exist. Aphasia, memory problems, and advanced-order cognitive dysfunctions similar to executive and visuospatial impairments are among these deficits; these frequently coincide with vascular cognitive impairment. Studies have demonstrated cognitive decline both before and after stroke, and vascular risk factors raise the threat of both stroke and cognitive decline.[8]

The need for stroke rehabilitation services is rising as strokes continue to be the primary cause of adult disability. Numerous large-scale intervention trials aimed at motor recovery report similar advancements in motor performance for both the intervention and control groups, though not always to the same degree. These indifferent outcomes could result from the tested interventions' lack of added benefit or the numerous difficulties in planning and carrying out extensive stroke rehabilitation trials. New approaches to patient selection, control interventions, and endpoint measures are strategies for enhancing the quality of trials. Rehabilitation techniques help stroke survivors recover their independence indeed, though research into stroke rehabilitation aims to enhance trials, interventions, and results.[9]

The main objective of this review study was to summarize robotic rehabilitation's effectiveness in managing stroke patients. This study provides valuable insight into the promising benefits of robot-assisted rehabilitation for improving the quality of life among individuals suffering from stroke.

METHODS

Search strategy: A comprehensive literature search was conducted across multiple databases, including keywords such as "robotic rehabilitation", "stroke", and "rehabilitation". The articles were searched in different databases including PUBMED, GOOGLE SCHOLAR, PEDRO, and COCHRANE LIBRARY.

Inclusion criteria: Inclusion criteria for study selection involved Randomized Controlled Trials and Pilot Studies published between 2017 and 2024.

Exclusion criteria: Exclusion criteria excluded systematic reviews, meta-analyses, and articles published before 2017.

Data extraction: Initial searches identified 87 relevant articles. These articles underwent screening, with 30 identified for this review study. The included articles compared outcomes of robotic rehabilitation interventions versus control groups in stroke patients. Data collection encompassed various parameters, such as the impact of robotic training on gait, balance, cognitive ability, and upper limb rehabilitation. Additionally, different components demonstrating the efficacy of robotic rehabilitation were reviewed.

RESULT

Effect of Robotic Rehabilitation on Gait

Kim et al. (2024) conducted a study titled "Simultaneous High-Definition Transcranial Direct Current Stimulation (HD-tDCS) and Robot-Assisted Gait Training in Stroke Patients".[10] The research utilized the Lokomat robotic device and involved 24 participants. These patients were split into the Real HD-tDCS set, and the Sham HD-tDCS set. In this Real HD-tDCS set, participants obtained robotic training alongside transcranial direct current stimulation, whereas the Sham HD-tDCS set underwent robotic drilling without the stimulation. Assessments using various measures such as the Functional Ambulation Category (FAC), Dynamic Gait Index (DGI), Fugl-Meyer Assessment (FMA), Timed-Up-and-Go (TUG) test, Berg Balance Scale (BBS), 10-Meter Walk Test (10MWT), Functional Reach Test, Visual Analog Scale (VAS), and Korean Modified BI (K-MBI) were conducted. The action spanned 10 sessions over four weeks. After four weeks, significant improvements were observed in all test parameters within the Real HD-tDCS set, whereas the Sham HD-tDCS set displayed no notable improvement. The Real HD-tDCS set exhibited multiple enhancements among physical functions, indicating the positive impact of combining robotic training with transcranial direct current stimulation.

Li et al., conducted a study titled "Effect of Robot-Assisted Gait Training on Motor and Walking Function in Patients with Subacute Stroke".[4] The research utilized the BEAR-H1 (wearable lower extremity exoskeleton robot) robotic equipment and included 36 patients aged 18 to 75. Patients were separated into two clusters: Cluster A, the experimental cohort, and Cluster B, the baseline cluster, which were delivered traditional therapy. Assessments were conducted using measures such as FAC, Mini-Mental State Questionnaire, Ashworth test, 6-Minute Walk assessment (6MWT), Functional Ambulatory Classification, Fugl-Meyer questionnaire for bottom extremity, and Modified Ashworth Scale. Both groups underwent exercises focusing on muscle strengthening, stretching, and balance for four weeks, twice a day for 1,800 seconds, five days out of seven days. After four weeks, improvements were observed in motor abilities, gait performance, and walking endurance in patients treated with BEAR-H1 compared to those receiving conventional therapy. This proposes that Robot-acquired Gait Training is more effective for people with subacute stroke.[4]

Longatelli et al. conducted a study titled “Robotic Exoskeleton Gait Training in Stroke”.[11] The study utilized robotic devices such as Ekso, Re-Walk, and Indego and included 29 contributors between 18–80 years old. Contributors were segregated into two bunches: The Control Bunch (CB), which received standard rehabilitation methods, and the Experimental Bunch (EB), which underwent a combination of conventional therapy and rehabilitation using an exoskeleton device. Assessments were conducted using the Modified Barthel Scale, Motricity Index, 10-meter walk test, 6-minute walk assessment, Functional Ambulatory Category, and Trunk Control Test. The intervention consisted of sessions conducted five times a week, each lasting 60 minutes, spanning over four weeks. Both groups demonstrated progress in their abilities (Capacity Score) after four weeks of intervention. The EB progress has been comparable to that of the CB after the experiment, with minor improvements observed in lower leg muscle activity during walking measurements.[11]

Maranesi et al. conducted a study titled “Robotic Intervention for Older Patients with Subacute Stroke”.[12] The study incorporated the G-EO System which is a robotic and the end-effector device aiding in walking therapy. Over 152 subjects, 65 years and above, have been involved in research. The study comprised the control group and a technology-based experimental set. The control group underwent a standard rehabilitation program, while the intervention group engaged in a robotic rehabilitation program utilizing the G-EO system alongside their conventional therapy. Assessments were conducted using measures such as the FAC, Modified Ashworth test, Short Form-12 (SF-12), Performance-Oriented Mobility test, Motricity Index (MI), Mini-Mental State Test, Rivermead Assessment, Barthel Scale, Clinical Dementia Rating, Activities-specific Balance Confidence Scale (ABC), Participation in Autonomy and Domestic Life, and gait analysis along with instrumental postural analysis. The intervention comprised sessions conducted thrice a week, with each session lasting 30 minutes, spanning over seven weeks. Additionally, the intervention group received an extra 20 minutes of treatment with the G-EO System during each session. After seven weeks, participants in both groups demonstrated improvements in various aspects, including reduced risk of falling, increased walking speed, decreased fear of falling, improved mobility, and enhanced performance in daily tasks. Notably, the group utilizing the G-EO system experienced further advantages, such as improved walking speed, better balance, reduced fear of falling, and increased acceptance of technological aids.[12]

Alingh et al., conducted a study titled “Training for Improvement of Propulsion Symmetry and Gait Speed in Chronic Stroke Patients”.[13] The study utilized the LOPES II, Demcon and MOOG BV, USA robotic devices. A total of 29 participants between 51–71 years old were interviewed for the research. The study consisted of a single group that received treatment using the LOPES II robotic device. Assessments were conducted using assessment tools such as the Hospital Anxiety and Depression Scale, Modified Ashworth Test, FMA, Functional Gait Assessment, Stroke Impact Assessment, Mini-Mental State Test, Medical Research Council (MRC) scale, 6-Minute Walk Test (6MWT), Star Cancellation Test, MI, and FAC. The exercise duration for the group was comprised of sessions conducted twice a week, with each session lasting 60 minutes and spanning over five weeks. After five weeks of treatment, participants experienced improved balance and coordination in walking, stronger leg movements, increased ankle flexibility on the weaker side, and enhanced overall walking speed, balance control, arm function, and cognitive abilities.[13]

Heng et al., in 2020, conducted a study titled “Changes in Balance, Gait, and Electroencephalography after Robot-Assisted Gait Training in Chronic Stroke Patients”.[14] The study utilized the MRG-P 100 HIWIN Robotic Gait Training System, India and included 24 partakers between 35 and 80 years. The survey involved the Traditional Group and the Robot-Assisted Gait Training (RAGT) group. The Traditional Group received standard physiotherapy rehabilitation, whereas the RAGT group received standard physiotherapy and robotic gait training. Assessments were conducted using the Berg Balance Assessment and the Timed “Up and Go” test. The intervention for both groups consisted of sessions conducted four times a week, with every sitting lasting 30–45 minutes, spanning over four weeks. Additionally, after the standard duration, the RAGT set acquired an extra 30 minutes of robotic gait exercise. After four weeks, the RAGT therapy resulted in a four-fold increase in balance improvements compared to usual care, indicating its superior effectiveness and potential added benefits in treating the condition.[14]

Kotov conducted a study titled "Robotic Restoration of Gait Function in Elderly Patients with Stroke".[15] The study utilized the ExoAtlet exoskeleton and Ortorent MOTO pedal trainer, Italy. A subtotal of 47 participants between the age of 52 and 74 were incorporated into the experiment. Participants were split into two bunches: ExoAtlet exoskeleton bunch, which received rehabilitation using the provided robotic device, and the Ortorent MOTO pedal trainer group, which underwent dynamic and ideal training for all extremities using the pedal trainer. Assessments were conducted using the MRC assessment, Modified Ashworth test, Berg Balance test, Hemiplegic Arm Shoulder Ability (HASA), 10-Meter Walk Test (10MWT), modified Rankin assessment, and BI. The exercise duration for both groups consisted of sessions conducted five days a week, each lasting 10–30 minutes, reliant on the participants' functional capacity, over two weeks. After two weeks, both groups experienced improvements in strength, balance, mobility, and walking pace. However, Group 1, utilizing the ExoAtlet exoskeleton, significantly improved more than Group 2. Group 1 also demonstrated reduced disabilities and increased daily function, which were more pronounced than those observed in Group 2. These findings suggest that both robotic training methods effectively improve gait and balance, with the ExoAtlet exoskeleton showing particular efficacy.[15]

Nolan et al., in the year 2020 conducted a study titled "Robotic Exoskeleton Gait Training During Acute Stroke Rehabilitation".[16] The study utilized a Robotic exoskeleton (Indigo Powered Exoskeleton) and involved 22 contributors within the customary age set of 59.6 years. The study comprised two groups of participants: the RE (Robotic Exoskeletons) +SOC (conventional Standard of Care) Group, which underwent robotic exoskeleton (RE) gait training as a component of their inpatient recovery program, and the conventional Standard of Care Set, which got standard rehabilitation treatments during their inpatient rehabilitation program. Assessments were conducted using the Modified Functional Classification, Modified Functional Evaluation, Walking Functional Classification, and Functional Independence Measure (FIM). The intervention consisted of sessions conducted thrice a week, each lasting 25 minutes, spanning over four weeks. Both groups demonstrated improvement in movement abilities after four weeks, but the RE+SOC group exhibited greater improvements than the SOC bunch. The RE+SOC bunch could engage in more intense walking practice without extending their training time, resulting in better recovery of their ability to perform daily tasks.[16]

Kim et al., conducted a study titled "Robotic-Assisted Gait Training for Balance and Lower Extremity Function in Patients with Infratentorial Stroke".[17] The study employed the Lokomat robotic orthosis and WALKBOT Mechanical-aided walking therapy and involved 19 participants with an average age of 47.4 years. Contributors have been divided into sets: Set A and Set B. Set A underwent four weeks of Resistance Agility Grappler Training combined with Cognitive Processing Therapy (CPT), after four weeks of CPT alone. In contrast, Set B received interventions oppositely: four weeks of CPT ensured by four weeks of RAGT combined with CPT. Conducted assessments using measures such as the Trunk Impairment Test, Fugl-Meyer Assessment for Lower Extremity (FMA-LE), Functional Electrical Stimulation (FES), 10-Meter Walk Test (10MWT), BBS Test, Scale for the Assessment and Rating of Ataxia (SARA), and FAC. The intervention consisted of sessions conducted five times a week, each lasting 30 minutes over four weeks. After a month, both groups demonstrated significant progress in maintaining balance while moving and standing still, lower body movement abilities (measured by FMA-LE), and coordination (measured by SARA). However, the group that underwent RAGT combined with conventional physical therapy (PT) showed a distinct advantage in maintaining balance while standing compared to the group receiving conventional PT alone. Additionally, while both groups showed improvements in walking ability (measured by FAC), the RAGT+CPT group showed more significant improvement in static balance (measured by BBS), and upper body movement abilities (measured by FMA-UE) improved slightly in both groups.[17]

Kim et al., examined the effects of "Effects of robot-assisted gait training for stroke patients"[18], utilizing robotic devices including the Gait Trainer, Lokomat, Chicago, United States, and Morning Walk, Korea. The study comprised 25 participants, with a mean age of 57.7 years in the trial cluster and 60.4 years in the traditional cluster. The research compared two cohorts: The Morning Walk®, Korea Group, where participants underwent 30 minutes of Techno-assisted walking rehabilitation with Morning Walk® along with 60 minutes of conventional PT per session, and the traditional cluster, which solely got 90 minutes of traditional PT. Evaluation tools employed encompassed the Modified Barthel Scale, Rivermead Mobility scale, Functional Ambulatory Category score, 10 Meter Walk examination, Berg Balance test, and MI for lower extremities (Motricity Index-Lower). The exercise regimen entailed sessions five times a week, each spanning 60 minutes, over three weeks. After completing the three-week treatment, both groups exhibited significant enhancements across all measured parameters. Notably, the Morning Walk® group demonstrated more pronounced improvements in leg movement (quantified by the Motricity Index-Lower score) and balance (evaluated through the BBS) than the control group. Moreover, both cohorts displayed advancements in walking speed (indicated by increased pace in the 10 Meter Walk assessment) and balance (as evidenced by elevated scores on the BBS.[18]

Effect of Robotic Rehabilitation on Balance

Giovannini, et al., conducted a survey titled "Robotic-Assisted Rehabilitation for Balance and Gait in Stroke Patients".[19] The study utilized the Hunova Movendo Technology srl robotic device, Italy, robotic platform, end-effector RAGT, and robotic balance platform. A total of 24 partakers having a mean age of 65 years were collected in the investigation. The investigation involved The Investigative Cluster (IC) and Regulation Cluster (RC). The partakers in the IC underwent specialized balance disorder rehabilitation using a robotic platform in addition to standard care. At the same time, those in the RC received only traditional treatment as per their daily routine, without the robotic platform intervention. Assessments were conducted using measures such as Motricity Scale for lower extremity, Short Physical Performance Battery (SPPB), Berg Balance test, TUG test, ABC (Activities- specific Balance Confidence) Scale, Walking Handicap test, FAC, 10-Meter Walk Test (10MWT), 6-Minute Walk Test (6MWT), Barthel Index for Modified Kitchens (BIMK), EQ-5D-5L questionnaire (EQ-50), Modified Fatigue Impact Scale (MFIs), Fatigue Severity Scale (FSS), Frontal Assessment Battery (FAB), Symbol Digit Modalities Test (SDMT), Digit Cancellation Test, Trail Making Test (TMT), and Tinetti Assessment Measure. The duration of the exercises was thrice a week, for 45 minutes, spanning over four weeks. At the end of the four-week intervention, both groups demonstrated improved balance, fatigue levels, quality of life, and physical and mental abilities. It was anticipated that the group receiving robotic-assisted therapy and regular therapy (Investigative Cluster) would show greater effectiveness than the group receiving only regular therapy (Regulation Cluster).[19]

Li et al., investigated a trial on "Effects of a Brain-Computer Interface-Operated Lower Limb Rehabilitation Robot on Motor Function Recovery in Patients with Stroke".[20] In this study, Brain-Computer Interface (BCI) technology was employed. Twenty-eight patients were taken in the trial with an average age of three and seven decades. Two groups were established: the BCI cluster and the Sham cluster. The BCI cluster received robotic exercise, physiotherapy, and medical treatments, while the Sham group only received physiotherapy and medical treatment. Assessment tools such as Levels of Cognitive Functioning Test for Adults, FMA-UE (Fugl-Meyer Assessment for Upper Extremity), FAC, MBI (Modified BI), Serum Brain-Derived Neurotrophic Factor (BDNF) Levels, FMA-LE (Fugl-Meyer Assessment for Lower Extremity) and neurophysiological variables incorporating Motor Evoked Potential latency and amplitude were utilized. The exercise regimen consisted of sessions conducted six days a week, each lasting 30 minutes, spanning four weeks. After four weeks, the BCI group demonstrated significant improvements in various abilities for stroke recovery patients. Specifically, cognitive abilities showed enhancement, as evidenced by improved Levels of Cognitive Functioning Scale (LCFS) scores indicating better cognitive function. While both groups exhibited similar improvements in upper limb motor functions, gait, and balance, the positive effect of BCI, especially for cognitive ability improvement, was highlighted.[20]

Chen et al., conducted a study titled "Effect of Telerehabilitation on Balance in Individuals with Chronic Stroke".[21]

The study utilized various robotic devices, including the Kinect Sensor, RAGT (Microsoft Corporation, Redmond, WA, USA), with a Virtual Reality (VR) system, Virtual Reality System, Exergaming Telerehabilitation System, and Interactive Self-Rehabilitation Programs. A gross of 30 participants with a mean age of six decades were enrolled in the trial. The study comprised two sets: the Manipulated set, which participated in a VR intervention program, and the Sham Set, which received traditional PT treatment. Assessments were conducted using the Berg Balance test, TUG, MI, FAC, and Modified Falls Efficacy Scale. The duration of the exercise was six times for four weeks, for 2,400 seconds, spanning over a month. Within four weeks, both the Sham and Manipulated sets demonstrated measurable improvements in balance and walking. However, the Experimental Set exhibited superior balance improvements. Both sets showed enhancements in BBS scores, indicating improved balance, while the Manipulated group notably reduced their TUG test times, suggesting enhanced mobility. The Manipulated set's significant advancements in balance and walking measures compared to the Sham set establish its superiority. Specifically, the Manipulated set improvements in BBS scores and TUG test times signify enhanced balance and mobility, respectively.[21]

De Luca et al., investigated title "Dynamic Stability and Trunk Control Improvements Following Robotic Balance and Core Stability Training in Chronic Stroke Survivors".[22] The study utilized the robotic device Hunova. A sum of 15 partakers in the investigation, with an average age of 59 years old in the robotic squad and 63 years old in the experimental squad. The study consisted of two squads: The Experimental Squad, which underwent a rehabilitation program using robots, and the Control Squad, which underwent conventional rehabilitation sessions led by physical therapists. Assessments were conducted using the BBS, Mini-Balance Evaluation Systems Test (Mini-BESTest), and Trunk Impairment Scale. The exercise duration for both groups was six times for four weeks, for 2,700 seconds, spanning five weeks. After five weeks of exercise, both groups demonstrated enhanced balance, walking abilities, arm function, and cognitive performance. However, the control group only showed significant improvement in their ability to maintain balance when reacting to unexpected disturbances, while the Experimental Group maintained their balance improvements, as assessed by the BBS, over time. Specifically, for the Experimental Group, there was an enhanced ability to step forward and backward confidently, as indicated by the Mini-BES Test. Additionally, statistically significant improvements in balance as documented in Berg Balance Scale (BBS) persisted over time, along with increased trunk control and stability during activities.[22]

Castelli et al., conducted a study titled "Robotic-Assisted Rehabilitation for Balance in Stroke Patients (ROAR-S): Effects of Cognitive, Motor, and Functional Outcome".[23] The study utilized the robotic device Hunova® Movendo Technology, srl, Genoa, Italy, a cutting-edge robot designed to aid in rehabilitation for core stability, balance, and lower body functions. This robotic platform is specifically designed to assess and treat the trunk and lower limbs, providing personalized therapy. The study involved 24 participants with an approximate age of 77 years old in the Hunova Crew (HuC) and 76 years old in the Conventional Crew (CoC). HuC group received special treatment with the Hunova robotic platform for balance problems, on top of the usual treatment recommended by doctors. The CoC group served as a comparison and received only the usual treatment recommended by doctors. Assessments were conducted using measures such as the FAC, EuroQol-5D (EQ-5D), Modified Fatigue Impact Scale (MFIs), Fatigue Severity Scale (FSS), Functional Ambulation Battery, SDMT, TMT, Berg Balance test, SPPB, Modified BI (MBI), ABC scale, Walking Handicap Scale, and other cognitive and motor assessments. The duration of the exercise was thrice a week. Treatment outcomes for both groups showed improvements in clinical scales, cognitive performance, balance, mobility, quality of life, and fatigue. The HuC group demonstrated further enhancements in motor skills, cognitive function, and overall well-being compared to the CoC group. Both groups experienced shared improvements in gait, including enhanced ambulation, increased speed in the Timed Up & Go test, and improved walking and sit-to-stand abilities under the SPPB. Additionally, both groups showed strengthened balance, as indicated by improvements in the BBS and SPPB balance sub-score.[23]

Effect of Robotic Rehabilitation on Cognitive Ability

Zhao et al., conducted a study titled "Effects of Training with a Brain-Computer Interface Controlled Robot on Rehabilitation Outcome in Patients with Subacute Stroke".[24] The study employed a BCI-controlled robotic device and Newton's ring to elicit Steady-State Motion Visual Evoked Potentials. A total of 33 participants ages 32 to 68 years old were taken for the experiment. Two groups formation took place: the Sham cluster and the BCI cluster. The Sham cluster received conventional physiotherapy, while the BCI cluster received BCI-based intelligence in addition to conventional physiotherapy. Assessments were conducted using the LOCTA, Fugl-Meyer Testing for the Lower Limb, FAC, FMA for the Upper Limb, Modified Barthel testing, and Serum BDNF levels. Both groups received therapies for four weeks, 1 time a day for half an hour, 12 days of two weeks. After a month, improvements were observed in cognitive function, lower limb motor function, increased levels of BDNF, and ambulation abilities in patients treated with BCI and conventional therapy compared to the Sham cluster. These findings suggest a positive effect of BCI in patients with subacute stroke.[24]

Torrisi et al., organized a review on "The role of hand robotic rehabilitation plus VR in improving cognitive function".[25] In this study, the AMADEO Robotic device, USA was utilized. 48 participants, with a typical age of 54 years old, were incorporated. The candidates were fractioned into two bands: the Manipulated and the Standard bands. The Manipulated band received treatment from the AMADEO robot, while the Standard band underwent conventional PT (Physiotherapy). Assessment tools such as Mini-Mental State Questionnaire, TMT, Stroop Test, Clock Drawing Test, RAVLT (Rey Auditory Verbal Learning Test), FMA, ARAT (Action Research Arm Test), BBT, NHPT, Jebsen-Taylor Hand Function Test, BI, FIM, MoCA (Montreal Cognitive Assessment), mRS (modified Rankin Scale), NEADL (Nottingham Extended Activities of Daily Living) and SIS (Stroke Impact Scale) were utilized for testing. The duration of the exercise was not specified in the provided information. After the treatment, the study demonstrated that participants who received robotic hand therapy (RHT) experienced greater improvement in cognitive abilities compared to those who received conventional hand therapy. Specifically, AHT enhanced attention, executive function, and visual-spatial skills. However, hand function improvement was similar for both groups.[25]

Aprile et al., carried out a survey on "Robotic Rehabilitation to Improve Cognitive Functions in Subjects with Stroke".[26] In this study, three robotic models—Motore, Amadeo, and Diego (Tyromotion and Humanware)—along with a sensor-based instrument called Pablo, were utilized. The study comprised 51 partakers with an average age of 64 years. Various cognitive assessment tools were employed, including the Tower of London for Executive Functions, SDMT for Attention and Processing Speed, Digit Span Task for Memory, Oxford Cognitive Screen, FMA for Upper Extremity, and Rey-Osterrieth Complex Figure Test. Participants underwent 30 sessions lasting 45 minutes each, conducted five days a week. Following these sessions, improvements were observed in cognitive functions, upper extremity motor functions, and performance in daily activities. This suggests that the combined effect of robotics and cognitive exercises contributes to patient recovery.[26]

Manuli et al., conducted a study on "Robotic Rehabilitation plus VR affect cognitive behavioral outcome in patients with chronic stroke".[27] This study used Computer Assisted Reality, Lokomat Nanos, and Lokomat Pro robotic devices, USA. The review included a whole of 90 individuals, with 30 individuals allocated to each group. Three distinct groups were established: Team 1, comprising the "Robotic Rehabilitation team with VR"; Team 2, consisting of the "Robotic Rehabilitation without VR"; and Team 3, receiving "conventional therapy". Assessment tools utilized in the study included the Montreal Cognitive Assessment, FIM Cognitive Subscale, Motor Subscale, Weigl Test, Short Form-12 Health Survey Total (Mental and Physical), Beck Depression Inventory-II, TMT Form, Visual Search and FAB. Each participant underwent 40 sessions of their respective treatments, followed by 40 sessions of physiotherapy. After the completion of these sessions, improvements were observed across all three groups in cognitive functioning, mood, executive functions, and activities of daily living (ADL). Nevertheless, Team 1 receiving robotic rehabilitation and VR demonstrated impressive enhancements in shifting skills, quality of life, selective assessment, and cognitive flexibility. This suggests that the combination of robotic rehabilitation and VR provides the most effective approach to cognitive rehabilitation.[27]

Effect of Robotic Rehabilitation on Upper Limb Management

Frisoli et al., conducted a study on "A randomized clinical control study on the efficacy of three-dimensional upper limb RE training in chronic stroke".[28] The study employed the Pnew-WREX, ARMin exoskeleton, and L-EXOS exoskeleton, Italy. Twenty-two people took part, segregated into two bunches: The Robotic bunch, which received treatment from the exoskeletons, and the CB, which underwent manual PT. Assessment tools such as BAT, FMA, and the Ashworth Scale were utilized. Exercise sessions were conducted thrice a week, each lasting 2,700 seconds, 6 times for four weeks. Following the 6-week period, the Robotic Group exhibited significant improvements in functional ability and task precision, indicating the positive effects of Robotic Rehabilitation compared to conventional therapy.[28]

Takebayashi et al., handled an analysis on "Robot-Assisted Training as Self-Training for Upper Limb Hemiplegia in Chronic Stroke".[29] The study focused on the use of the ReoGo-J upper limb extremity equipment, Brazil. The study involved 129 participants aged between 58 and 60. Three groups were established: the baseline assembly, who underwent basic physiotherapy techniques with self-improvement methodologies; the Robot Training (RT) assembly, which underwent robot-assisted training of ReoGo-J unit before standard occupational therapy; and the Movement Therapy (MT) Group, wherein participants engaged in occupational techniques based on Constraint-Induced Movement Therapy, task-oriented therapy, and robot-assisted therapy. Various assessment tools were utilized, including MAS, Performance Test for Upper Limb Functions, Motor Evaluation in Vascular Hemiplegia, Research Analysis of SIS, FMA, Action Research Arm Test, MI for Muscle Strength, Active Range of Joint Motion Assessment, SIS for Quality of Life. Exercise sessions were conducted thrice weekly, each lasting for an hour for two and a half months. After the intervention, RT assembly demonstrated the most significant improvement in FMA-UE scores, indicating the highest benefit. Additionally, the RT Group exhibited the greatest enhancement in upper limb function compared to the other groups.[29]

Budhota et al., conducted the following study on "Robotic Assisted Upper Limb Training in Stroke".[30] The study utilized the H-MAN robotic equipment, USA. Forty-four participants, encompassing a range of ages from 21 to 85, were encapsulated for investigation. Participants were fragmented into two squads: The robotic therapy squad, which received combined therapy of H-MAN robotic and conventional physiotherapy, and the conventional therapy (CT) squad, which received only conventional therapy. Assessment tools such as FMA, VAS, MAS, MMSE, LTA, CTA, ARAT, and GS were employed. The RT squad underwent 60 minutes of H-MAN training, after half an hour of traditional techniques, at the same time, the CT squad received one and a half hours of traditional techniques. Both squads participated in sessions lasting 90 minutes each, three sessions a week for one and a half months. After the 6-week experiment, participants in the RT squad showcased growth in motor function and movement smoothness compared to the CT squad. Additionally, combination therapy reduced the workload demand on therapists.[30]

Shi et al., conducted a study on "Effects of a Soft Robotic Hand for Hand Rehabilitation in Chronic Stroke Survivors."[31] The study utilized the VAEDA robotic device. Sixteen participants aged 56, were collected in the search, which consisted of a single group. Assessment tools such as BBT, MAS, FMA-UE, ARAT, and Maximum Voluntary Grip Strength test were employed. Exercise sessions were conducted seven days a week, with every session approximating 60 minutes, over six weeks. After a 6-week intervention, a significant improvement in test scores was observed, indicating the effectiveness of robotic exercises for hand rehabilitation in chronic stroke survivors.[31]

Li et al., conducted a study titled "Efficacy of Robotic Priming with Bilateral Approach in Stroke Rehabilitation".[32] The research employed the Bi-Manu-Trace robotic device and involved 31 participants having a mean age of 55. Two groups were formed: the Robotic Primed Mirror Therapy crew (RMT) and the Robotic Primed Bilateral Upper Limb Training crew (RBULT). RMT crew participants underwent robotic training and mirror therapy, whereas in the RBULT group, participants received robotic training and bilateral upper limb training. Assessments were conducted using the robotic Neurological Severity Test, Chedoke Arm and Hand Activity Inventory, and accelerometer. The intervention consisted of sessions conducted six times in two weeks, with each training lasting 2,400 to 2,700 seconds over six weeks. After six weeks, the research findings indicated that the group receiving robotic priming with MT demonstrated a better outcome in motor function and arm use when matched to the crew receiving robotic priming with bilateral upper limb training. Therefore, combining robotic training with mirror therapy may improve motor function and arm functionality for stroke patients.[32]

Guillen-Climent et al., conducted a study titled "Use of MERLIN in Stroke Patients: A Robotic Device Based on Serious Games for Upper Limb Rehabilitation in Home Settings".[33] This study utilized the AA Robotic device, Italy, MERLIN robotic device, and Arm Assist robotic system. There were nine engagers between the ages of 41 and 84. The study comprised only one group, which received training from the MERLIN robotic system. Assessments using the Modified Ashworth Assessment and Fugl-Meyer scale were conducted. The exercise duration was thrice a week, for 30 minutes each session, spanning over three weeks. After three weeks, significant improvements were observed in upper limb coordination and overall motor function score.[33]

Ranzani et al., explored "Neurocognitive robot-assisted rehabilitation of hand function".[34] The study utilized the ReHapticKnob device. Thirty-three participants, covering ages from 18 to 19, were covered in the study, with 14 participants in the Robotic Group and 13 in the Control Group. Assessment tools such as FMA-UE, FMA-WH, FMA-SE, MAS, EmNSA-T, EmNSA-P, VAS, LCF-P, NIHSS, GoodGlass Kalpan Assessment, and Albert Test were employed. The Control Group underwent exercises 2–3 sessions a week for 30–45 minutes, whereas the Robotic Group engaged with set of 3, 2 times a week for 2,700 seconds. Both groups had kept track of assessments at 8 weeks and 32 weeks. The study concluded that robotic training yields outcomes comparable to Neurocognitive therapy, suggesting its potential as an alternative treatment approach for hand function rehabilitation.[34]

Aprile et al., executed a study, "Upper Limb Robotic Rehabilitation After Stroke".[35] In this study, various robotic devices were utilized: Motore, a robotic device facilitating assisted and unassisted flat motion of elbow and shoulder joints; Amadeo, supporting assisted and unassisted bending and straightening movements of fingers; Pablo, a sensor-based system enabling independent three-dimensional motion of wrist, shoulder, and elbow joints; and Diego, a device aiding three-dimensional, one/two-handed motion of the shoulder joint with arm weight assistance. The study encompassed a total of 224 members between the ages of 4 and 85, segregated in two sets: The Robotic set (RS), undergoing therapy with robotic devices targeting shoulder, elbow, hand, and wrist joints, and the Conventional set (CS), receiving traditional treatment focusing on upper limb function improvement, sensorimotor control restoration, and muscle stiffness reduction. Assessment tools such as FMA, MI, MRC, MAS, DN4, NRC, mRI, FAT, ARAT, SF 36-PCS, and SF-36-MCS were employed. Treatment comprised daily 45-minute episodes, five times a week, over the month, for both sets. Additionally, conventional rehabilitation sessions occurred six times a week, each lasting 45 minutes, during the same month. After four weeks of treatment, both the Robotic set and the Conventional set demonstrated improvement in several areas. The average FMA score increase was 8.50 for RS and 8.57 for CS, surpassing the clinically meaningful improvement threshold of 5 points. RG exhibited greater enhancement in upper extremity strength, as calculated by the Motricity Test, compared to CS, and maintained this advantage at the treatment's conclusion.[35]

Huang et al., reviewed "The comparison of the rehabilitation effectiveness of neuromuscular electrical stimulation robotic hand training and pure robotic hand training after stroke".[36] In this study, a variety of robotic devices were employed, including the Hybrid neuroprosthesis for the upper extremity, robotic hand, EMG-Driven robotic hand, EMG-driven neuromuscular electrical stimulation (NMES) robotic hand, and electromechanical wrist robot assistive system. Fifteen engagers represented the age of 57 for the experimental team and 6 decades for the pure team, were contained in the review. The study encompassed two participant cohorts: the NMES cohort, which utilized a robotic hand controlled by electromyography (EMG)-driven NMES, and the Pure cohort, which utilized a robotic hand without additional NMES stimulation. Assessment tools such as FIM, MAS, ARAT, and FMA were employed. The exercise regimen consisted of sessions conducted thrice a week for 30 minutes over three months. After three months, it was observed that neuromuscular electrical stimulation (NMES) improved hand function in paralyzed patients when contrasted to a pure cohort without stimulation. NMES cohort exhibited a notable increase in hand function assessment scores (HFAS) and a substantial reduction in elbow, wrist, and finger muscle stiffness. The NMES group maintained these improvements in hand function, whereas the control group's hand function assessment score declined at the 12-week follow-up. The review emphasizes on upper limb function, particularly hand function, demonstrated significant benefits from NMES correlated to the control team.[36]

Franceschini et al., facilitated an examination on "Upper limb robot-assisted rehabilitation versus PT on subacute stroke patients".[37] In this study, robotic devices were employed, namely the InMotion2 robotic system and Planer end-effector robots. A total of 48 participants were involved, where the robotic crew is 74 years old and the conventional crew with an average age of 7. Involved parties were fragmented into two crews: The Experimental Crew, utilizing InMotion2 robotic system, Chicago for upper body rehabilitation, involving goal-based, two-dimensional reaching tasks, and the control crew, receiving conventional upper body PT. CT activities included stretching assistance, arm and shoulder training, and reaching activities with therapist guidance. Assessment tools such as FMA for upper extremity, lax range of motion, Modified Ashworth test for shoulder stiffness, and Modified Ashworth Scale for elbow stiffness were utilized. The exercise regimen consisted of sessions conducted five times a week, each lasting 45 minutes, spanning over six weeks. After six weeks, both crews illustrated improved upper extremity working, as assessed by the Fugl-Meyer measurement. Additionally, the Experimental Group improved shoulder and elbow stiffness (measured by the Modified Ashworth Scale) and arm flexibility (measured by passive range of motion). The Experimental Crew illustrated superior improvement in these areas compared to the Control crew, which only showed improvement in shoulder stiffness.[37]

Qian et al., conducted a study on "Early Stroke Rehabilitation of the Upper Limb Assisted with an Electromyography-Driven Neuromuscular Electrical Stimulation-Robotic Arm".[38] This study utilized various robotic devices, including the EMG-driven NMES robotic arm, Rehabilitation robot ARMin II, USA. Electromyography-driven robot, and electromechanical wrist robot-assisted system device. Twenty-four participants had a typical age of 54 for the exploratory cluster and 6.4 decades for the Control cluster. The study comprised two participant groups: the NMES-Robot Group, which underwent training using a robotic arm delivering NMES, and the Control cluster, which received conventional rehabilitation treatments focused on the upper limb. Assessment tools such as the Action Research Arm Examination, Function Independence Assessment, Modified Ashworth Scale and Fugl-Meyer Examination were employed. The exercise regimen consisted of sessions conducted five times a week, each lasting 40 minutes, spanning over four weeks. Following a month of drill, the exploratory cluster (NMES robot) and the control cluster exhibited substantial improvements in FMA, MAS, ARAT, and FIM. Nevertheless, the NMES-robot cluster demonstrated significantly grander improvements in FMA scores, particularly for the wrist and hand. This improvement has not been seen for control cluster, displaying superior efficacy of NMES-RT in enhancing wrist and hand function.[38]

DISCUSSION

The current literature review critically investigated 30 articles to highlight the effects of robotic rehabilitation on stroke. In addition to the basic impact of traditional physiotherapy in the form of manual techniques and a basic exercise program that was approved as an effective modality for the improvement of gait, balance, cognition and upper limb this study investigates for the beneficial effects of robotic rehabilitation for stroke survivors. Bruni et al.'s research highlighted significant improvements in gait parameters.[39] They emphasized the importance of patients engaging in more intense and repetitive training sessions, enhancing brain flexibility and supporting motor recovery. Task-Oriented Training through robotic rehabilitation offers personalized sessions tailored to each patient's specific needs, focusing on enhancing particular motor skills and functional movements to improve overall mobility. Additionally, certain robotic systems provide augmented feedback, crucial in enhancing motor learning and performance by offering immediate feedback on movement quality and progress. As a result, robotic gait rehabilitation can effectively enhance walking speed, balance, and coordination, ultimately leading to improved gait function and greater independence in daily tasks.[39] Similarly, the reviewed articles examined various gait parameters, including step and stride length, gait speed, cadence, motor skills, and functional ability. Moreover, notable improvements were observed in gold-standard assessment scales such as the BBS, 10-Minute Walk Test, and Time-Up-and-Go test. Specific scales like the Fugl Mayer Assessment and DGI were also used to assess and track progress accurately. Zheng et al.'s research highlights the improvement in balance parameters, emphasizing that enhancing muscle strength is a key benefit of robot-acquired training for patients suffering from a stroke.[40] This training provides targeted resistance and controlled movements, enhancing balance function. Additionally, coordination improves as patients are guided through various tasks and exercises, helping them relearn and refine the motor skills necessary for balance control. The Recurring and work-oriented quality of training with robot-acquired training promotes neural plasticity, enabling the brain Restructure and establish fresh neural pathways, thereby aiding in balance function improvement during the recovery process. The therapy also offers patients a variety of sensory inputs, including proprioceptive and vestibular feedback, crucial for maintaining balance and spatial awareness.[40]

Moreover, postural control can be enhanced in stroke patients through robotic assistance, targeting specific muscle groups and adjusting their center of gravity, essential for maintaining balance during various activities. The aforementioned articles discussed balance parameters such as static and dynamic balance and ambulation. Additionally, improvements were noted in parameters like swing amplitude, center of pressure, and speed of oscillation. Significant improvements were observed in gold-standard scales such as the BBS and Fugl Meter Balance Scale. The research by Aminov et al., highlighted significant improvements in cognitive abilities, underscoring the potential advantages of robotic rehabilitation in enhancing cognitive function among stroke patients.[41] For example, VR interventions show promise in boosting cognitive function and memory by leveraging the connection between motor skills and cognitive capabilities. However, further in-depth investigations are necessary to fully understand the extent of these benefits and refine treatment plans for cognitive rehabilitation using robotic technology.[41]

The articles above discuss improvements in major components such as attention, visuomotor skills, memory, cognitive flexibility, executive functions, shifting skills, and enhancements in LOCTA score. Additionally, improvements in mood were also observed.

Bertani et al's research sheds light on the significant improvement in upper limb functionality.[42] They highlight how robotic therapy holds promise in enhancing motor function recovery in the upper limb, especially for individuals grappling with chronic strokes. Positive reorganization in the motor cortex can lead to better outcomes in arm function. Additionally, advanced robotics assisting in therapy through focused and repetitive exercises can greatly expedite recovery after a brain injury, improving upper limb function. Robotic technology can also enhance flexor synergies, coordination, and speed in the affected upper limb while improving the sense and understanding of the shoulder, arm, and forearm. Moreover, robotic-assisted therapy can alleviate joint pain in the upper limb, enhancing comfort and mobility during rehabilitation.[42]

The articles discussed above underscore improvements in various parameters of the upper limb, including motor functions, coordination, and sensory function. Significant enhancements were noted in gold-standard assessment scales such as the Fugl Meyer Assessment, Action Reach Arm Test, and Modified Ashworth Scale. Furthermore, additional scales such as the Biconical Activity test and MI were also utilized, highlighting the comprehensive evaluation of upper limb functionality.

Robotic rehabilitation for stroke patients has been extensively studied recently, with research post—2018 highlighting its feasibility and potential benefits. Feasibility studies have demonstrated the practicality of robotic interventions in various settings. For instance, a 2018 pilot study evaluated the use of a robotic glove for hand rehabilitation in hemiplegic stroke patients at home. The findings indicated that the intervention was both feasible and safe, with 81% of participants completing the program. Significant improvements were observed in hand motor function, dexterity, and strength. Similarly, research from 2020 assessed the use of a single-joint Hybrid Assistive Limb (HAL-SJ) robot for upper limb rehabilitation in subacute stroke patients with varying severity levels. This study concluded that robot-assisted rehabilitation is feasible across different severity groups, with the most notable improvements in patients with moderate impairments.

The efficacy of robotic rehabilitation is further supported by studies integrating multiple therapeutic modalities. A 2021 study introduced the perSonalized UPper Extremity Rehabilitation (SUPER) program, which combined robotics, VR, and NMES. This program, tailored to individual functional levels, demonstrated feasibility and effectiveness, with 64% of participants showing clinically significant improvements in upper extremity function. Additionally, recent developments in neural interface technology, such as Neuralink's BCI trials, have explored controlling robotic arms through brain implants. While primarily targeting individuals with paralysis, this technology holds promising implications for stroke rehabilitation by enabling direct neural control of assistive devices.

This study has several limitations, including limited access to the databases, leading to the inclusion of fewer studies. Secondly, a quality appraisal of the included studies was not performed.

Future recommendations include high-quality randomized controlled trials to reach any firm conclusion regarding the effectiveness of robotic rehabilitation in the resolution of post-stroke survivors' symptoms.

CONCLUSION

In conclusion, recent research underscores the feasibility and safety of robotic rehabilitation for stroke patients, with significant functional improvements and high patient compliance. Advancements in integrating robotics with other modalities and neural interface technologies further enhance the potential of robotic rehabilitation in stroke recovery. The motive behind this study was to show that including robotic rehabilitation with other techniques can result in similar advantages to rigorous training. Analysis of the existing data indicates that robotic therapy can improve walking, balance, thinking, memory, coordination, daily tasks, motor abilities, and posture management. In the end, all of these areas may experience enhancements by implementing robotic rehabilitation. However, more studies are required to confirm the existing findings.

AUTHOR CONTRIBUTIONS

All the authors contributed equally in the conduct of the review study.

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There is no conflict of interest as reported by the authors.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the ethical guidelines.

FURTHER DISCLOSURE

Not applicable.

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