



Enhancing Recovery in Stroke Patients through Robotic-Assisted Therapy

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Abstract : Stroke, defined by the World Health Organization as a sudden disturbance in cerebral function due to vascular origin, is a leading cause of death and disability globally. Ischemic stroke, caused by a blockage in blood flow, and hemorrhagic stroke, resulting from vessel rupture, both significantly affect neurological functions, including motor control and balance. Stroke survivors often experience muscle weakness, spasticity, abnormal gait, and balance impairment, contributing to decreased mobility, increased fall risk, and a reduced quality of life. Despite advancements in rehabilitation strategies, many stroke survivors struggle with walking and balance issues months after the event.

Rehabilitation efforts, particularly those focused on gait and balance, are essential for improving functional outcomes and quality of life. However, traditional therapy approaches, which are labor-intensive and limited by the severity of impairment, may not suffice for all patients. Robotic-assisted gait training (RAGT) has emerged as a promising alternative, providing patients with task-focused, consistent, and high-volume training. RAGT reduces the physical burden on therapists and offers real-time feedback for patients, enabling more effective rehabilitation. Various robotic devices, including exoskeletons and end-effector robots, have been developed to support gait training, and their efficacy in improving gait function has been demonstrated in clinical trials.

This study aimed to evaluate the impact of RAGT on motor recovery and functional outcomes in stroke patients. The results showed that the experimental group (RAGT) demonstrated significant improvements in gait ability, balance, and independence, compared to the control group (conventional therapy). Males performed slightly better in the dFAC (1.6 vs. 1.4) and dBBS (1.3 vs. 1.1) categories, suggesting a small advantage in these areas. However, females outperformed males significantly in the dFIM category (2 vs. 1.3), indicating better performance in this domain. In the MP category, males had a much higher score (1.4 vs. 0.7), showing a substantial difference in favor of males. In the dFAC category, young individuals performed significantly better (1.9) compared to older individuals (0.8), indicating a strong advantage in this domain, likely reflecting superior physical resilience and neuroplasticity in younger participants. In the dBBS category, young individuals also outperformed older ones, with scores of 1.4 and 1.2, respectively. While the difference is less pronounced here, it still suggests that younger participants have an edge in balance or similar tasks. In the dFIM category, younger participants scored 1.4 compared to 1.1 for older participants, again reflecting a noticeable, though smaller, advantage. Finally, in the MP category, young participants showed a significant lead (1.8) over older individuals (1.3), which could point to better motor performance and adaptability in younger age groups.

Initiating rehabilitation within the first 6 months leads to the most significant improvements in balance (dBBS) and motor performance (MP). While rehabilitation initiated 6-12 months post-stroke can still yield substantial benefits, particularly in balance, delaying therapy beyond one-year results in markedly reduced recovery outcomes. FAC improved across all categories, and BBS and FIM scores showed significant gains, particularly in the early rehabilitation phases. While both groups improved in balance and activities of daily living (ADL), the experimental group had statistically greater improvements in BBS and FIM scores. Although gait improvements in terms of FAC grades were not statistically significant, combining RAGT with conventional therapy appeared more effective than either treatment alone. The findings suggest that RAGT is superior to conventional physiotherapy for improving balance and accelerating locomotor recovery, especially in younger patients and those in the early post-stroke phase. Integrating

RAGT into rehabilitation programs can optimize functional outcomes for stroke survivors, providing more effective and intensive therapy.

I. INTRODUCTION

According to the World Health Organization, a Stroke is defined as an accident to the brain with "rapidly developing clinical signs of focal or global disturbance to cerebral function, with symptoms lasting 24 hours or longer, or leading to death, with no apparent cause other than of vascular origin and includes cerebral infarction, intracerebral hemorrhage, and subarachnoid hemorrhage". Stroke or cerebrovascular accident (CVA) is the sudden loss of neurological function caused by an interruption of the blood flow to the brain. The pathological background for stroke may either be ischemic or hemorrhagic disturbances of the cerebral blood circulation. Ischemic stroke is the most common type, affecting about 80% of individuals with stroke, and results when a clot blocks or impairs blood flow, depriving the brain of essential oxygen and nutrients [1]. Hemorrhagic stroke occurs when blood vessels rupture, causing leakage of blood in or around the brain. Worldwide, cerebrovascular accidents (stroke) are the second leading cause of death and the third leading cause of disability. Globally, 70% of strokes and 87% of both stroke-related deaths and disability-adjusted life years occur in low- and middle-income countries. Over the last four decades, the stroke incidence in low and middle-income countries has more than doubled [2]. Low and middle-income countries are associated with a persistent cycle of inadequate access to quality food and housing, financial stress, poor health behaviors, threats to personal safety, and lack of access to care. These circumstances, in turn, increase the health risks to low-income people, even in the absence of serious health problems. Identifying these risks is challenging for healthcare providers but ultimately necessary for managing patients' health care, preventing more serious health problems, and improving health outcomes [3].

The effects of stroke vary from person to person based on the type, severity, location, and number of strokes. The brain is very complex. Each area of the brain is responsible for a specific function or ability. When an area of the brain is damaged from a stroke, the loss of normal function of part of the body may occur. This may result in a disability [4].

Stroke leads to damage to motor cortices and their descending corticospinal tracts and subsequent muscle weakness. On the other hand, brainstem descending pathways and the intraspinal motor network are disinhibited and become hyperexcitable [5]. The wide range and hierarchy of post-stroke hemiplegic gait impairments are a reflection of the mechanical consequences of muscle weakness, spasticity, abnormal synergistic activation, and their interactions. Walking dysfunction occurs at a very high prevalence in stroke survivors. Human walking is often taken for granted, but it is mediated by complicated neural control mechanisms [6], [7]. The automatic process includes the brainstem descending pathways and the intraspinal locomotor network. The ability to walk independently is a prerequisite for most daily activities. The Capacity to walk in a community setting requires the ability to walk at speeds that enable an individual to cross the street in the time allotted by pedestrian lights, step on and off a moving walkway, in and out of automatic doors, walk around furniture, under and over objects and negotiate kerbs [8]. A walking velocity of 1.1-1.5m/s is considered fast enough to function as a pedestrian in different environmental and social contexts. It has been reported that only 7% of patients discharged from rehabilitation met the criteria for community walking, which included the ability to walk 500m continuously at a speed that would enable them to cross a road safely. Balance is the ability to maintain the line of gravity within the base of support with minimal postural sway [9]. The control of human balance is a comprehensive process relying on integrating visual, vestibular and somatosensory inputs to the central nervous system. It is reported that about 83% of stroke survivors suffer from balance impairment [10]. Balance impairment is characterised by short supporting time and differences between two sides of the body and slow walking speed, which may increase the risk of falls. Fear of falling can contribute to a sedentary lifestyle and increased disability, which means lower quality of life. Almost two-thirds of stroke survivors have initial mobility deficits, and six months after stroke, more than 30% of survivors still cannot walk independently. Walking difficulties can have a major impact on stroke survivors, limiting their ability to independently perform daily activities and having a negative impact on their quality of life [11]. Loss of balance when walking is common after stroke, with 70% of stroke survivors living at home reported to fall within a year of their stroke. Muscle weakness and loss of voluntary movements are common problems immediately following a stroke, and these contribute to reduced walking speed, which is a characteristic sign of post-stroke gait. Marked temporal and spatial inter-limb asymmetries are also common, occurring in 48% to 82% and 44% to 62% of post-stroke subjects, respectively; these symmetries are correlated with impaired standing balance control during gait [12]. Generally, a key rehabilitation goal for stroke survivors is to improve walking, to enhance opportunities for participation in social activities and return to work. Various rehabilitation approaches, founded on theories and knowledge of motor recovery and brain neuroplasticity, have been used to improve balance and, consequently, gait after stroke [13]. However, there continues to be considerable controversy and debate about the relative effectiveness of different approaches to rehabilitation. In order to provide optimal rehabilitation to an individual stroke survivor, a health professional needs to be able to select the most appropriate intervention based on knowledge of the evidence of the effectiveness of different interventions and taking into account patient preference, resources, and clinical setting. Patients with stroke have gait and balance problems related to joint mobility and stability, muscle tone, muscle weakness and endurance, and loss of proprioception. While most patients regain independent ambulatory function within 6 months, problems with balance continue even after 6 months. Impairment of balance ability makes the daily life of a stroke patient difficult, and the fear of falls and other secondary disabilities is likely to aggravate the state of disability [14]. In particular, poor sitting balance in the acute stages after stroke indicates a poor prognosis for motor recovery in performing routine activities such as wheelchair transfer and eating. For These reasons, balance ability is the most important component in rehabilitation. Robust balance can be achieved through either direct balance training for enhancing balance performance, or gait training. Of these two intervention methods, gait training is predominantly a direct approach requiring the involvement of a therapist, such as body weight-supported treadmill training and overground walking training. However, such overground walking therapies are not likely to provide hemiplegic stroke patients with continuous and consistent training, and they impose substantial physical burdens on even skilled therapists. Moreover, high-severity stroke patients incapable of walking owing to weakness and poor coordination cannot benefit from overground walking therapies [15][16].

To address these limitations, robot-assisted gait training (RAGT) was introduced, and it is attracting interest. RAGT has the advantage of enabling gait training for otherwise non-trainable patients by assisting their ambulatory functions with exoskeleton assistive devices to enable task-focused training and providing the patient with regular feedback. Gait machines, consisting either of a robot-driven orthosis and a treadmill or an electromechanical solution with two driven footplates simulating the phases of gait,

were intended to reduce the therapists' exertions [17]. Gait machines are intended to relieve therapeutic effort to assist the patient's gait, and in combination with physiotherapy (PT), they affect superior gait ability in most stroke trials and meta-analyses. The machines, offering practice up to 1,000 steps per session, either used an exoskeleton or an end-effector approach [18], [19]. In recent years, robotic devices have been widely utilized to replace the manpower and physical needs of therapists in the field of neurological rehabilitation [20]. It also allows patients with nerve damage to receive a lot of exercise. Robotic Rehabilitation devices can be divided based on the driven principles: exoskeleton robot (e.utilizedg. Lokomat, AutoAmbulator, LOPES, ALEX) , and end-effector robot(e.g. G-EO-systems, Gait Trainer, Gait Master) Type. The exoskeleton robot is equipped with programmable drives or passive elements which flex the knees and hips during the swing phase, whereas with the end- effector robot principle the feet are placed on foot plates, whose trajectories simulate the stance and swing phases [21].

Rehabilitation robots for stroke are usually designed to adapt to the patient's functional level, and this process needs considerable technical flexibility. These Techniques include but are not limited to passive and adaptive exercise, active assisted, active constrained, and resistive exercise [22]. The rehabilitation robot can apply constant therapy for long periods and allows for continuous monitoring of patient performance and progression that can be delivered to the therapist. During the past decade, many articles investigating the effect of electromechanical walking-assist devices, both exoskeletal and end-effector types, on the gait function of stroke patients were published. Rehabilitation robots and electromechanical-assisted training devices for stroke patients have been used in locomotive restoration [23]. Most of these devices incorporate body weight support along with treadmills or foot platforms. It was found that the exoskeletal type of robot devices was primarily used, although the end-effector type was also utilized. The advantage of robotic devices over conventional gait training is that they reduce the need for intensive therapist support [24], [25]. Robotic aids for rehabilitation hold considerable promise but have not yet achieved strong clinical recommendations. Barriers to adoption include the limited data on efficacy, the single-purpose design of existing robots, financial considerations, and clinician's lack of familiarity with this technology. Nevertheless, the use of rehabilitation robotics has grown rapidly in recent decades, and a number of therapeutic rehabilitation robots have become available for research purposes and also for clinical use. To maximize the benefit of robotic gait training, further studies should be performed for patient selection, optimal device type according to the functional level, training protocols, etc. [26]

II. AIM

To assess the impact of robotic-assisted therapy on the motor recovery and functional outcomes of stroke patients during the rehabilitation process.

III. METHODOLOGY

Select a diverse group of stroke patients with varying degrees of impairment. Randomly assign participants to either the robotic-assisted therapy group or a conventional therapy group. The robotic-assisted therapy group undergoes sessions with a specialized robotic device, G-EO, designed for lower limb rehabilitation with high intensity and high repetition movement along with standard conventional rehabilitation exercises. The conventional therapy group receives only standard conventional rehabilitation exercises without robotic assistance.



Figure 1. Robotic-assisted gait training using a device made by Reha Technology. He is supported by a harness and grips handrails for stability. His feet are positioned on footplates, which guide his movements to simulate walking on a treadmill.

In this study, we used the GEO Robotic GAIT trainer from Reha Technologies, as depicted in Figures 1& 2. The GEO Gait Trainer is equipped with a dynamic weight support system and adjustable settings to tailor the training experience to the patient's needs. Key features include real-time feedback, adjustable robotic support for individualized training, and the ability to simulate over-ground walking. The GEO Gait Trainer also allows therapists to monitor and adjust therapy parameters (Cadence, step length, degree of dorsiflexion, degree of plantarflexions), ensuring that the patient's progress is tracked and optimized for better outcomes.



Figure 2. Robotic-assisted gait training device from Reha Technology, designed to help individuals with mobility impairments through guided movement and repetitive gait simulation. The setup includes a harness system for body support and footplates that simulate

3.1 Interventions

a. Group A- Robotic-assisted therapy group

One therapist assists the patients with putting on the harness while sitting in their wheelchairs. Get the patient onto the robotic-assisted gait training system in the wheelchair using a ramp from the rear. Fix the patient's feet on the plates, hoist the patient, and attach the lateral ropes. Set the therapy parameters memorized by the robotic-assisted gait training system computer. During each session, the patients practiced 20 to 25 min of simulated floor walking followed by 5 to 10 min of repetitive simulated stair climbing and down. The patient practiced a minimum of 300 steps on the simulated floor and climbed a minimum of 30 steps on the simulated stair during each session. During the training, the therapist manually assisted knee extension while standing in front of the patient if needed. The treatment parameters were noted for each session.

b. Group B - Conventional Therapy Group

The patient was given stretching and strengthening programs. After that, balance training exercises started, which included Heel raises, Sidestepping, Heel-toe walking, Single-leg standing, Backward walking, Balance board exercise, and Vestibular ball training. Afterward, the patient was given conventional gait training methods, including Symmetrical weight-bearing training, Stepping exercises, Tandem walking, Parallel bar walking, and Hurdle walkover.

3.2 Statistical Analysis

To derive statistical inferences regarding the application of robotics in stroke rehabilitation, data were collected on key parameters such as rehabilitation period duration, Functional Ambulation Category (FAC), Berg Balance Scale (BBS), Functional Independence Measure (FIM), manual physiotherapy sessions (MP), as well as patient demographics (gender and age). A total of 152 cases were analyzed, consisting of 130 males and 22 females. Patients were categorized into two age groups: young (up to 50 years, with an average age of 42.2 years) and old (above 50 years, with an average age of 74.9 years).

The FAC, BBS, and FIM scores were recorded at admission and discharge to measure improvements. A greater positive difference in these scores indicates better recovery. The cases were divided into two groups: those who received GEO robotic sessions and those who did not. The differences in FAC, BBS, and FIM scores between admission and discharge (denoted as ΔFAC , ΔBBS , and ΔFIM) were calculated to assess the impact of GEO sessions on rehabilitation outcomes. A ratio of these differences between cases with and without GEO sessions was used to quantify the influence of GEO sessions. If the ratio exceeds 1, it indicates that GEO sessions provided a beneficial effect, whereas a ratio below 1 suggests limited effectiveness of GEO in that scenario.

For each patient, the improvement in the Functional Ambulation Category (FAC), Berg Balance Scale (BBS), and Functional Independence Measure (FIM) can be calculated as the difference between the values at discharge and admission:

$$\Delta FAC = FAC_{\text{discharge}} - FAC_{\text{admission}}$$

$$\Delta BBS = BBS_{\text{discharge}} - BBS_{\text{admission}}$$

$$\Delta FIM = FIM_{\text{discharge}} - FIM_{\text{admission}}$$

These differences indicate the level of improvement, with larger values suggesting better outcomes. Then the average improvement for patients who received GEO sessions and those who did not can be calculated separately. Let N_{GEO} be the number of patients who received GEO sessions and N_{NoGEO} the number of patients who did not. The average improvement for each group can be calculated as:

$$\frac{\Delta FAC_{GEO}}{N_{GEO}} = \frac{1}{N_{GEO}} \sum_{i=1}^{N_{GEO}} \Delta FAC_i$$

$$\frac{\Delta FAC_{NoGEO}}{N_{NoGEO}} = \frac{1}{N_{NoGEO}} \sum_{i=1}^{N_{NoGEO}} \Delta FAC_i$$

Similarly, the average improvements for BBS and FIM are calculated in both groups:

$$\frac{\Delta BBS_{GEO}}{N_{GEO}} = \frac{1}{N_{GEO}} \sum_{i=1}^{N_{GEO}} \Delta BBS_i, \quad \frac{\Delta BBS_{NoGEO}}{N_{NoGEO}} = \frac{1}{N_{NoGEO}} \sum_{i=1}^{N_{NoGEO}} \Delta BBS_i$$

$$\frac{\Delta FIM_{GEO}}{N_{GEO}} = \frac{1}{N_{GEO}} \sum_{i=1}^{N_{GEO}} \Delta FIM_i, \quad \frac{\Delta FIM_{NoGEO}}{N_{NoGEO}} = \frac{1}{N_{NoGEO}} \sum_{i=1}^{N_{NoGEO}} \Delta FIM_i$$

Then the effectiveness of GEO sessions can be assessed by calculating the ratio of the average improvements between the GEO group and the NoGEO group for each parameter:

$$dFAC = \frac{\Delta FAC_{GEO}}{\Delta FAC_{NoGEO}}$$

$$dBBS = \frac{\Delta BBS_{GEO}}{\Delta BBS_{NoGEO}}$$

$$dFIM = \frac{\Delta FIM_{GEO}}{\Delta FIM_{NoGEO}}$$

If $FAC, dBBS, dFIM > 1$, it indicates that GEO sessions positively affected patient improvement. If $dFAC, BBS, dFIM < 1$, the GEO sessions may be less effective or have no significant advantage compared to manual rehabilitation.

Finally, a t-test or ANOVA can be performed to check whether the differences in improvements between the GEO and NoGEO groups are statistically significant:

$$t = \frac{\Delta FAC_{GEO} - \Delta FAC_{NoGEO}}{\sqrt{\frac{S_{GEO}^2}{N_{GEO}} + \frac{S_{NoGEO}^2}{N_{NoGEO}}}}$$

Here, S_{GEO}^2 and S_{NoGEO}^2 are the variances of the improvements in the GEO and NoGEO groups, respectively. The same test can be applied for BBS and FIM.

IV. RESULTS AND DISCUSSION

The bar chart shown in Figure 3 compares the results of motor function recovery for males and females in two groups: "Zero GS - without GEO" and "Non Zero GS- with GEO " based on three outcomes—dFAC (difference in Functional Ambulation Category), dBBS (difference in Berg Balance Scale), and dFIM (difference in Functional Independence Measure). In the female group, there is a clear difference between the Zero GS and Non Zero GS groups in terms of balance (dBBS) and functional independence (dFIM), while improvements in gait (dFAC) are minimal for both groups. Both the Zero GS and Non Zero GS groups show little to no improvement in gait ability, with no significant differences between the groups. This indicates that gait recovery in females was not substantially impacted by the intervention, regardless of their GS category. However, there is a noticeable improvement in balance (BBS), with the Non Zero GS group showing slightly better results compared to the Zero GS group. This suggests that females in the Non Zero GS group responded better to the intervention in terms of balance recovery. The most striking difference is seen in functional independence (FIM), where the Non Zero GS group shows a dramatic improvement compared to the Zero GS group. This indicates that females with Non Zero GS experienced significant gains in their ability to perform daily activities independently, which could have a substantial impact on their quality of life.



Figure 3. Comparison of functional improvements in gait (dFAC), balance (dBBS), and functional independence (dFIM) between Zero GS and Non Zero GS groups for female (n=22) and male (n=130) stroke patients.

In the male group, the patterns differ slightly from the female group, with both groups showing improvements across all measures, though the trends are not as distinct. Similar to the female group, there is minimal improvement in gait ability (FAC) for both Zero GS and Non Zero GS groups, indicating that gait recovery was generally limited for males, regardless of GS status. Both groups show significant improvements in balance, with the Non Zero GS group performing marginally better than the Zero GS group. This suggests that the Non Zero GS group may have benefited slightly more from the intervention in terms of balance restoration. In contrast to the female group, the Zero GS group in males shows better improvement in functional independence compared to the Non Zero GS group. This indicates that males with Zero GS had a higher recovery in their ability to perform daily activities independently, even outperforming those in the Non Zero GS group.

Females show the most significant improvement in FIM. Males also demonstrate good gains in FIM and BBS, with some differences between the groups. FAC improvements are minimal for both genders across groups. Some Improvement in BBS and FIM found without delineating from manual physio.

4.1 Male vs. female with GEO

The graph in Figure 4 indicates gender-based differences in the four categories measured, suggesting that males generally score higher in dFAC, dBBS, and MP, while females excel in dFIM. The results could point to specific gender-based physiological or performance differences that might relate to physical abilities or the type of tasks being measured. Males performed slightly better in the dFAC (1.6 vs. 1.4) and dBBS (1.3 vs. 1.1) categories, suggesting a small advantage in these areas. However, females outperformed males significantly in the dFIM category (2 vs. 1.3), indicating better performance in this domain. In the MP category, males had a much higher score (1.4 vs. 0.7), showing a substantial difference in favor of males. These results suggest that while males generally show better outcomes in some areas, females excel in others. The results could point to specific gender-based physiological or performance differences that might relate to physical abilities or the type of tasks being measured.

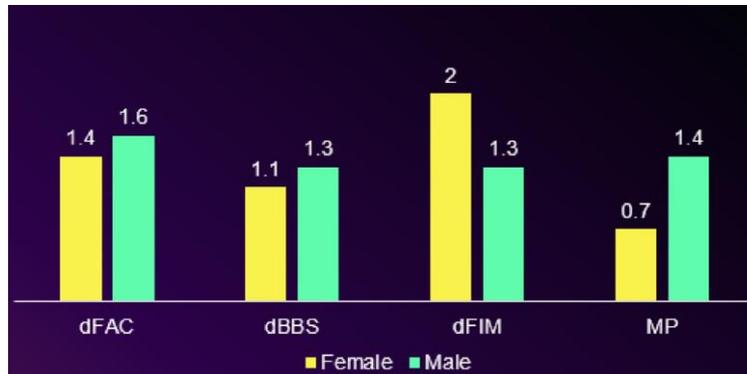


Figure 4. Comparison of male and female performance across four categories (dFAC, dBBS, dFIM, MP).

4.2 Young Vs Old GEO

Age plays a significant role in the effectiveness of gait training and stroke rehabilitation, impacting recovery outcomes, speed of progress, and the overall rehabilitation process. The brain's ability to reorganize and adapt, memory, attention, and processing speed, is generally sharper known as neuroplasticity, muscle strength, flexibility, and cardiovascular health tends to be more robust in younger individuals. This allows for faster recovery of motor functions during gait training and stroke rehabilitation. With age, neuroplasticity diminishes. As a result, older individuals may experience slower recovery and require longer rehabilitation periods. However, neuroplasticity does not cease completely with age, and older adults can still make significant progress with consistent and targeted gait training.

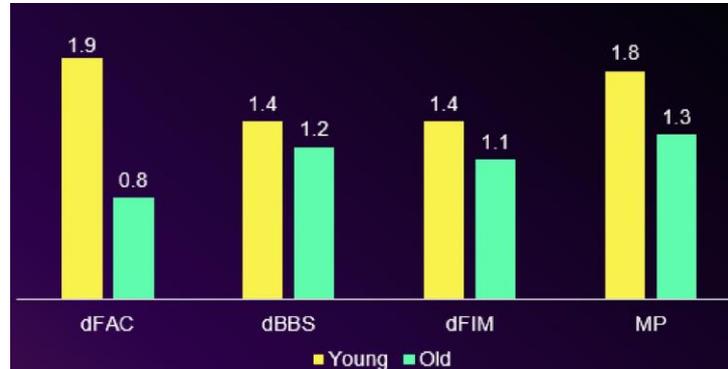


Figure 5. Comparison of performance between young and older individuals across four categories (dFAC, dBBS, dFIM, MP).

The graph in Figure 5 compares the performance between young and older individuals across four categories: dFAC, dBBS, dFIM, and MP. In the dFAC category, young individuals performed significantly better (1.9) compared to older individuals (0.8), indicating a strong advantage in this domain, likely reflecting superior physical resilience and neuroplasticity in younger participants. In the dBBS category, young individuals also outperformed older ones, with scores of 1.4 and 1.2, respectively. While the difference is less pronounced here, it still suggests that younger participants have an edge in balance or similar tasks. In the dFIM category, younger participants scored 1.4 compared to 1.1 for older participants, again reflecting a noticeable, though smaller, advantage. Finally, in the MP category, young participants showed a significant lead (1.8) over older individuals (1.3), which could point to better motor performance and adaptability in younger age groups. The results suggest that younger individuals generally outperform older ones across all categories, highlighting the influence of age on gait training and rehabilitation. The pronounced difference in the dFAC and MP categories could be attributed to the physical decline associated with aging, including reduced muscle strength, flexibility, and neuroplasticity, which are key to mobility and motor performance. The relatively smaller differences in dBBS and dFIM suggest that with focused training, older adults can still achieve considerable improvements, though at a slower pace than their younger counterparts.

4.3 Post-stroke time before admission

The time between stroke onset and admission to rehabilitation, often referred to as the "post-stroke time," plays a crucial role in determining the effectiveness and outcomes of stroke rehabilitation. The brain undergoes a heightened period of neuroplasticity immediately after a stroke, where it is more capable of reorganizing and forming new neural connections. This window of increased plasticity, often within the first 3 months, is considered the optimal time for stroke rehabilitation. Early initiation of therapy can maximize functional recovery, including motor skills, cognitive function, and activities of daily living (ADL). Early rehabilitation reduces the risk of secondary complications such as pressure ulcers, deep vein thrombosis, muscle wasting, and contractures. By mobilizing patients early and engaging them in therapeutic exercises, rehabilitation can prevent these issues from compounding the disability caused by the stroke itself. Early initiation of rehabilitation is linked to better long-term outcomes. Patients who begin rehabilitation promptly are more likely to regain independence, return to work or social activities, and have an overall better quality of life. Timely rehabilitation can offer not just physical benefits but also emotional and social support. Early participation in group therapies or rehabilitation programs provides patients with encouragement, a sense of community, and a support network, which are essential for long-term recovery.

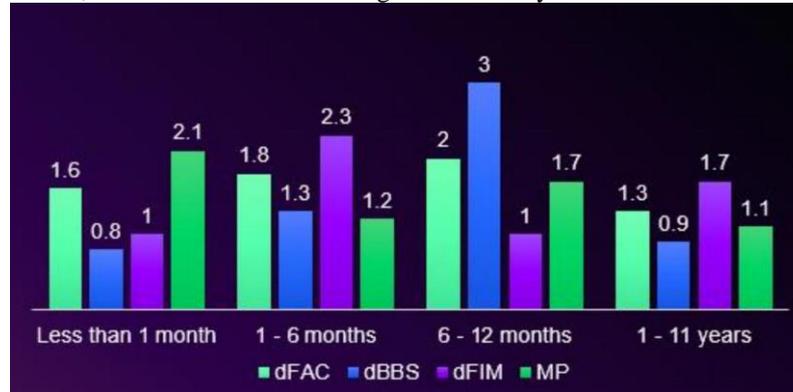


Figure 6. Impact of post-stroke time before rehabilitation admission on performance in four categories: dFAC, dBBS, dFIM, and MP.

The graph illustrates the impact of post-stroke time before rehabilitation admission on four performance categories: dFAC, dBBS, dFIM, and MP, across different time periods (less than 1 month, 1-6 months, 6-12 months, and 1-11 years). dFAC and MP are higher in this group (1.6 and 1, respectively), indicating a moderate advantage in functional ambulation and motor performance when rehabilitation is initiated early. However, dBBS (0.8) and dFIM (1) show lower scores, suggesting some balance and functional independence challenges even with early intervention. Rehabilitation started within this window shows significant improvement in all categories, with dBBS peaking at 2.1, dFAC at 1.8, and MP at 1.3. This suggests that recovery in balance and motor performance is optimized when therapy begins within the first six months post-stroke. The data show a notable peak in dBBS (3), indicating substantial improvement in balance during this time frame. Additionally, dFAC (2), dFIM (1.2), and MP (1.7) scores are strong, demonstrating significant recovery potential even with delayed rehabilitation up to one year after stroke. When rehabilitation is delayed beyond a year, performance scores drop across all categories. dFAC (1.7), dBBS (0.9), dFIM (1.3), and MP (1.1) are lower compared to earlier admission windows, reflecting a decline in recovery outcomes the longer rehabilitation is delayed. The results highlight the critical role of early rehabilitation in post-stroke recovery. Initiating rehabilitation within the first 6 months leads to the most significant improvements in balance (dBBS) and motor performance (MP). While rehabilitation initiated 6-12 months post-stroke can still yield substantial benefits, particularly in balance, delaying therapy beyond one year results in markedly reduced recovery outcomes. These findings underscore the importance of early and consistent intervention in stroke rehabilitation to optimize functional and physical recovery.

Special Cases

1. 59 years old male patient with a diagnosis of acute right MCA infarct showed a significant improvement after treatment. His initial FAC score was 1, initial BBS was 18, and initial FIM score was 85; he had undergone 112 sessions of manual physiotherapy with 16 sessions of GEO training for a total of 124 days of treatment. After treatment his FAC improved to 4, BBS to 23 and FIM score significantly improved to 99.

2. 44 years old male patient with a diagnosis of severe acute right hemorrhagic stroke showed significant improvements in treatment outcomes. After initial assessment he is having a FAC score 0, BBS=45, FIM=53. he underwent 502 sessions of manual physiotherapy with 75 sessions of GEO training, for a total of 205 days. After treatment he have showed a marked improvement in his treatment outcomes. His FAC score improved to 5, BBS score to 52 and FIM score to 113.

3. 55 years old male patient having a diagnosis of severe left MCA infarct had found with a significant improvement with treatment. His initial assessment FAC score was 0, BBS was 35, and FIM was 58 He had undergone 191 manual physiotherapy sessions with 17 sessions of GEO training for a total of 83 days of treatment. After treatment, he had better outcomes; post-treatment, his FAC score improved to 5, his BBS score to 51, and his FIM score to 84.

4. A 48-year-old male patient diagnosed with chronic left MCA infarct had found better outcomes after treatment. Before treatment, he had an FAC score of 1, BBS=20, and FIM=75; he underwent 156 sessions of manual physiotherapy with 59 sessions of GEO training for a total of 156 days. after treatment, he came with significant outcomes: his treatment FAC improved to 5, his BBS score improved to 29, and his FIM score improved to 85.

5. A 47-year-old male patient with acute right ACA ischemic stroke was found to have significant improvements with treatment. His initial assessment FAC score was 1, BBS was 45, and FIM was 70 He had undergone 107 manual physiotherapy sessions with 18 sessions of GEO training for a total of 83 days of treatment. After treatment, he had better outcomes; post-treatment, his FAC score improved to 5, his BBS score to 50, and his FIM score to 126.

6. A 33-year-old male patient with severely affected acute left MCA ischemic stroke was found to have significant improvements with treatment. His initial assessment FAC score was 1, BBS was 20, and FIM was 93. He had undergone 480 manual physiotherapy sessions with 40 sessions of GEO training for a total of 480 days of treatment. After treatment, he had better outcomes; post-treatment, his FAC score improved to 4, his BBS score to 26, and his FIM score to 119. Variables for the period of 5 years.

IV. DISCUSSION

Stroke is one of the most common causes of acquired adult disability. The majority of stroke survivors have mobility difficulties such as poor standing, decreased walking speed, balance disturbances, and increased risk of falls. Patients with stroke have gait and balance problems related to joint mobility and stability, muscle tone, muscle weakness and endurance, and loss of proprioception. Improving mobility, walking, and balance are the main goals of stroke rehabilitation.

The primary purpose of this study was to investigate the effects of robot-assisted gait training on the gait of chronic stroke patients. Previous studies have shown that the robot-assisted gait training technique is effective in stroke rehabilitation. As there are very few studies that have used robotic-assisted gait training for stroke rehabilitation, this study is intended to show the effects of robotic-assisted gait training on improving gait among adults suffering from a stroke.

Gait machines, consisting either of a robot-driven orthosis and a treadmill or an electromechanical solution with two driven footplates simulating the phases of gait, were intended to reduce the therapist's exertions. Gait machines are intended to relieve therapeutic effort to assist the patient's gait. Combined with physiotherapy (PT), they affect superior gait ability in most stroke trials and meta-analyses. The machines, offering practice up to 1,000 steps per session, used an exoskeleton or an end-effector approach. For sub-acute stroke patients, the Robotic gait device significantly improved walking ability compared to treadmill training in a randomized cross-over study.

Previous controlled trials on locomotor therapy with the help of a treadmill and manual assistance failed to show superior gait function and walking velocity in non-ambulatory stroke patients. The patients may have made too few steps on the belt, attributable to the effort of the therapists (e.g. when setting the paretic limbs). None of the trials reported exact numbers. Repetitive locomotor training aligns with modern principles of motor learning, favoring a task-specific, repetitive approach. The so-called motor relearning program, a physiotherapy approach also based on task-oriented treatment principles, proved to be better than the Bobath approach concerning improving motor functions in acute stroke patients.

According to a study on severe stroke patients, RAGT was more efficient than regular ambulation therapy in improving the functions necessary for ambulation, such as proprioceptive balance control, lower extremity mobility, and endurance. In the stroke population, common impairments such as poor balance, weakness, malalignment, joint instability, and abnormal tone could decrease movement efficiency and act as a hurdle for functional improvement. RAGT helps stroke survivors overcome such problems by allowing them to practice typical gait patterns, temporarily reduce their body weight to achieve normal alignment, assist with foot clearance, and promote an automated intensive walking training program. The robotic system was well suited to produce intensive, task-oriented motor training for moving the patient's limbs.

The superior effects of RAGT can be attributed to the following reasons: more steps were practiced per session, symmetrical gait can be facilitated, and particle step length symmetry is better. Moreover, in the RAGT group, faster training speeds are possible, along with an increased duration of the training, which could aid with aerobic metabolism and improve cardiovascular training, increase muscle mass and decrease fat mass, and reduce the complications of immobilization. Furthermore, it is cost-effective in the long run and induces optimal joint kinematics during gait. These improvements are possible with RAGT because of body weight adjustments, speed control, and increasing or decreasing guidance forces applied on the affected side.

The results of the current study provide evidence that the robot-assisted gait trainer, which could be used for early rehabilitation after stroke onset, could significantly shorten the ambulation-dependence time when compared with conventional overground gait training. Supportive results also indicated that patients with subacute stroke who underwent gait training robot assisted gait trainer gained superior ambulatory ability than patients who underwent gait training using conventional physical therapy only. The findings showed clinical significance for an intensive 8-week intervention that used a robot assisted gait trainer for accelerating locomotor recovery in patients after stroke.

Figure 1 compares motor function recovery in males and females across two groups: "Zero GS - without GEO" and "Non Zero GS - with GEO," focusing on dFAC (gait), dBBS (balance), and dFIM (independence). In females, balance and independence improved significantly in the Non Zero GS group, while both groups saw minimal gait improvements. For males, both groups showed progress in balance and independence, though the Zero GS group had better functional independence. Across both genders, gait improvements were minimal, while balance and independence showed notable gains, especially in females. Some improvements were achieved without manual physiotherapy interventions.

The graph in Figure 2 highlights gender differences across four measured categories. Males scored higher in dFAC, dBBS, and MP, while females excelled in dFIM. Males showed a slight advantage in dFAC (1.6 vs. 1.4) and dBBS (1.3 vs. 1.1), while females significantly outperformed males in dFIM (2 vs. 1.3). In the MP category, males scored substantially higher (1.4 vs. 0.7). These findings suggest that gender-based physiological or performance differences may influence the outcomes in different tasks. Age significantly affects the outcomes of gait training and stroke rehabilitation, influencing recovery speed and overall progress. Younger individuals generally benefit from sharper neuroplasticity, stronger muscles, greater flexibility, and better cardiovascular health, leading to faster motor function recovery. As neuroplasticity declines with age, older adults may experience slower progress and require extended rehabilitation. However, with consistent and targeted training, they can still make significant gains. A comparison of young and older participants in categories like dFAC, dBBS, dFIM, and MP shows that younger individuals consistently perform better, particularly in mobility and motor performance. However, older adults can still achieve improvements with focused effort.

The time between stroke onset and admission to rehabilitation, known as the "post-stroke time," is critical in determining rehabilitation outcomes. The brain experiences increased neuroplasticity shortly after a stroke, particularly within the first three months, making it the ideal time for therapy. Early rehabilitation maximizes recovery of motor skills, cognitive function, and daily living activities. It also reduces the risk of secondary complications like pressure ulcers and muscle wasting. Patients who start rehabilitation early tend to have better long-term outcomes, regaining independence and improving their quality of life both physically and emotionally.

V. CONCLUSION

Gait ability also improved to a significant extent in the experimental group compared with the control group. Females showed improvement in FAC, BBS, and FIM. Results in FIM are very remarkable. Males show considerable improvements in FAC. Some Improvement in BBS and FIM was found without delineating from manual physio. Young patients showed improvement in FAC. Results in FAC of young patients using geo sessions are remarkable compared with older patients. Older patients didn't show considerable improvements. FAC showed better results with geo in all the categories, though not evident in the first category. BBS showed some results in the 1–6-month category and excellent results in the 6-12 month category. FIM showed excellent results in 1-6 month and 1–11-year categories. At the end of the interventions, both groups showed improved balance and ability to perform ADL. The statistical analysis revealed that the experimental group showed statistically more significant improvements in BBS and FIM scores than the control group. Even though the experimental group showed promising improvements in gait ability, the analysis revealed that the results were not statistically significant when considering FAC grades. Even though there is no statistically clear evidence due to considerable heterogeneity between studies, combining RAGT and conventional treatment could lead to better outcomes than the two techniques performed singularly. Therefore, on a clinical basis, RAGT and conventional treatment should be performed together when both are available in the case of post-stroke patients. From these results, it can be inferred that RAGT is superior to conventional physiotherapy as a treatment method for improving balance and gait. The results of the current study provide evidence that the robot-assisted gait trainer, which could be used for early rehabilitation after stroke onset, could significantly shorten the ambulation-dependence time compared with conventional overground gait training. Supportive results indicate that patients with subacute stroke at a young age who underwent gait training on a robot-assisted gait trainer gained superior ambulatory ability within 6-12 months than patients who underwent gait training using conventional physical therapy only. The findings showed clinical significance for intensive rehabilitation with a robot-assisted gait trainer in accelerating locomotor recovery in patients after stroke.

VI. DECLARATIONS

We hereby declare that this work is based on a case study utilizing anonymized patient records, and no direct patient interaction or intervention was involved. As this study solely involves retrospective data analysis of existing records without the use of identifiable personal information, it does not require ethical approval or adherence to specific ethical guidelines.

The data were processed and analyzed in accordance with standard practices to ensure confidentiality and integrity. No experimental procedures or interventions were conducted as part of this work.

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