Efficacy of Advanced Robotic and Virtual Therapy in the Treatment of Acute and Subacute Stroke Patients: a Feasibility Study

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Abstract: The aim of this study is to compare the effectiveness of advanced robotic therapy, virtual therapy and conventional physiotherapy in the rehabilitation of patients with acute and subacute stroke. In addition, we aim to further demonstrate the importance of an early mobilisation exercise program in the management of acute stroke patients. Participants (first-time ischaemic stroke patients in acute or subacute stages) were randomly divided into three equal groups (n=10 persons/group): a robot-assisted early mobilisation + virtual reality therapy (ROB+VR) group, a robot-assisted early mobilisation + conventional physiotherapy (ROB+FIZ) group, and a conventional physiotherapy (CON) group. Each group performed a 3-week-long training program (1 hour/session, 5 days/week). The results were measured before and after the exercise. The primary outcome measure used was the modified Rankin Scale (mRS) which indicates the severity of disability in daily activities and measures the degree of independence of the individual. The secondary outcomes were measured by the EuroQoL 5 dimensions questionnaire 5 levels version (EQ-5D-5L), the Berg Balance Scale (BBS), the Barthel Index (BI), and the 6-minute walking test (6mWT). All the three groups showed improvements in most outcomes. The scores for BI, EQ-5D-5L, and mRS showed significant improvements in quality of life. Comparing the groups, the ROB+VR group showed the greatest *improvement in the scores in almost all of the tests. From the test scores, the 6-minute walk test had the highest improvement at the end of the therapy (94.58% improvement). Our results show that early robotic mobilization, followed by a movement program, combined with a virtual reality therapy, significantly improve both the speed and quality of rehabilitation after a stroke.*

Keywords: acute stroke; early mobilization; virtual therapy

1 Introduction

Today, stroke is one of the most common leading causes of death in many countries. One of the most probable reasons for this is the ageing population and the lack of prevention strategies with which these mortality rates could be improved. It is predicted that the number of people with stroke could rise to as many as 1.5 million by 2025, due not only to the ageing of the population but also to the increasing rate of the disease among young people [1]. The WHO defines stroke as a disease as follows: "Stroke is a rapidly developing clinical syndrome characterized by global or focal disturbance of blood supply to the brain, lasting more than 24 hours or causing death, with no demonstrable cause other than a lesion in the cerebral vasculature". Beyond being one of the most common causes of death, stroke is also a leading contributor to long-term disability worldwide. This condition imposes significant health, social, and financial burdens on individuals and society alike. Patients often require prolonged and intensive rehabilitation to regain functional independence, which places a substantial demand on inpatient rehabilitation teams. The societal costs include not only direct medical expenses but also indirect costs related to lost productivity and the need for ongoing caregiving. About 40% of patients suffer functional impairment after stroke onset, and 15-30% of them experience severe motor, sensory, cognitive, perceptual and/or language impairments as well. However, the most common symptom is hemiplegia which occurs in 85% of the cases and will result in impaired upper and/or lower limb functions and loss of motor skills. This impairment will also significantly affect balance and the ability to carry out daily activities [2]. In most cases, the onset of stroke could be prevented if society were given detailed information about exactly what and how they can do to stay healthy. Of course, it is also a key factor that the individual has the motivation to take actions in order to improve their health and not just to try to regain it after an illness or disorder has already developed.

As the number of stroke survivors increases, even in younger age groups, the need to improve rehabilitation has become more and more pressing. In order to start this process, in addition to medical science, it is essential to integrate the latest recommendations from health and sports sciences into rehabilitation so that the treatments should be as complex as possible. [3] The rehabilitation process following a stroke is typically long and gradual, as a significant percentage of patients are left with some degree of functional impairment that diminishes their quality of life. Addressing these impairments not only demands a high level of motivation from both patients and rehabilitation professionals but also requires a substantial investment of time, energy, specialized expertise, and unwavering perseverance to achieve meaningful improvements. This condition affects multiple areas of the body with varying symptom severity between individuals, making it crucial for treatments to be well-coordinated, collaboratively implemented, and tailored to the specific needs of each patient. [4] [5]

The most important treatments are the physical (mobility therapy, exercise) and the cognitive (speech, memory, attention, motivation) therapies. These and many others (occupational, social, educational) will help the rehabilitated persons to resume their lifestyles, to carry out their daily activities independently or with as little assistance as possible and to lead a life of full value again [6]. Neurorehabilitation, a specialized form of rehabilitation that focuses on restoring the nervous system's functionality, is an essential basis for post-stroke recovery. This process involves interventions designed to enhance neuroplasticity, enabling the brain to reorganize and form new connections to compensate for lost functions. By targeting both cognitive and motor functions simultaneously, neurorehabilitation fosters a holistic approach to recovery, addressing the interconnected nature of neurological deficits. As highlighted by recent research, integrating neurorehabilitation strategies significantly improves outcomes for stroke survivors [7]. The regeneration of neuro-muscular connections is essential for the recovery of locomotor lesions and mobility difficulties caused by stroke and requires tasks that stimulate the neurobiological processes. This is called neuroplasticity, where the synaptic connections of the nervous system are constantly being rebuilt and rearranged. This enables people to learn new skills or relearn the lost functions [8] [9]. Neurorehabilitation will harness this capacity of the nervous system, thereby increasing the effectiveness of the rehabilitation. An essential tool for neurorehabilitation is to link visual stimuli and cognitive functions with motor functions [10]. In post-stroke rehabilitation, the integration of multiple therapeutic modalities, such as physical therapy, cognitive training, and neurorehabilitation techniques, has demonstrated more significant improvements in patients' functional outcomes compared to the application of individual therapies in isolation. This synergistic approach enhances recovery by addressing the multifaceted deficits caused by stroke, as evidenced by studies highlighting the benefits of multimodal interventions for motor and cognitive improvements. [11] [12]. Recently, virtual reality (VR) has burst onto the scientific scene as an innovative therapy, and a growing body of research has demonstrated its beneficial effects in the rehabilitation of neurological patients [13-15]. VR programs are highly effective in improving motor coordination, stamina, reaction time, reflexes, and spatial and temporal awareness [16] [17]. In addition, virtual therapy is a proven method for various neurological patients, such as multiple sclerosis or Parkinson’s disease [18-22]. Early mobilization basically means moving the patients according to their current conditions, thus preventing any complications from developing. It is common at patients that thrombosis, decubitus ulcers, pneumonia or even contracture are developed, as consequences of immobilization [23]. To prevent these, early mobilization is a key factor, but this can often be extremely demanding for a specialist [24].

Robotic devices are excellent tools of avoiding these problems where the therapist will not move the patients until they will be able to move independently, but the devices can be used to do this more easily and efficiently [25-27]. A commonly used robotic mobility device is the Motomed, a motor-driven and software-controlled machine that makes it easy to perform passive movement or even active resistance training on both the lower and upper limbs. The biggest advantage of the Motomed is that it can be used at early mobilization as it requires lower level of preparation than other rehabilitation devices. On the device, one can choose from a variety of programs, with a particular focus on treating a specific set of symptoms of a disease or improving a function, such as strength training or relaxation. During each program, both patient and therapist receive continuous feedback on the current performance, such as the symmetry between the two limbs or the resistance to drive the machine, which can trigger an immediate response from the patient to pay more attention during the therapy.

The primary aim of our research was to investigate the impact of a rehabilitation exercise program for stroke survivors that demonstrates the benefits of early mobilization using robotic devices and measures the effectiveness of conventional physiotherapy alone and in combination with virtual reality therapy. Our goal was to initiate a robot-assisted mobilization program for the patients in the very first days in order to demonstrate the importance of early mobilization at acute stroke.

2 Methods

One of the important aspects of our research was the observation of the effects of the used therapies on the quality of life, including the degree of self-care, the ability to perform activities of daily living, and the severity of disability. The other important aspect was the improvement of motor function where we were mainly looking at stroke-induced changes in gait, for which we wanted to demonstrate the improvement as a result of the exercise program.

2.1 The Design of the Research and the Sampling Method

The present study is a single-center, quantitative, randomized, controlled, single-blinded clinical trial, in which participants were selected from the neurology department and the neurorehabilitation unit of the Kaposi Mór Teaching Hospital in Somogy County. Our research was conducted between February 2024 and March 2024. According to the inclusion criteria, we selected patients with a neurologist diagnosis of first-time stroke detected by CT or MRI scan, an acute stage of stroke at the time of study entry, and mobility and postural difficulties (≥2) as defined by a modified Rankin scale score. The exclusion criteria were the following: history of stroke; resting blood pressure <120 or >160 mm Hg; orthostatic hypotension; severe heart disease; carotid artery stenosis; hemophilia; traumatic brain injury; seizure disorder; uncontrolled diabetes; abnormal EEG; abnormal blood panel; severe visual or hearing impairment; irregular medication regimen; severe aphasia; severe sensory dysfunction; severe orthopedic problems; neurological conditions affecting motor functions; severe addictive disorders (alcohol, drugs); Berg Balance scale score ≤32; Barthel index score ≤70; unable to walk at least 100 m within 6 minutes with or without assistance; unable to understand verbal instructions; already participating in a self-directed or formal group exercise program other than physical therapy. All participants gave written informed consent before the study started and the Institutional Research Ethics Committee approved the registered study protocol. The sample size of our study, once the criteria were met, was finally 30 participants in total (n=30). The participants were completely randomly selected and then allocated uniformly into the three study groups.

2.2 Characteristics of the Participants

In our research, a total of 30 people were selected in line with the exclusion criteria. They were equally divided into three groups of 10: ROB+VR (n=10), ROB+FIZ (n=10), CON (n=10). The proportion of women and men was different during the survey (female n=16, male n=14), and was also random at the group level as follows: ROB+VR (female n=6, male n=4), ROB+ FIZ (female n=7, male n=3), CON (female n=7, male n=3). The average age of the participants was 66.3 years (±1.33). Only ischemic stroke occurred at all of the examined patients. A total of 22 people (73.3%) had left-sided involvement, 5 people (16.6%) had right-sided involvement, and 3 people (9.9%) had strokes involving the cerebellum. From the patients with left hemisphere involvement 52% suffered a medial stroke, 25% a temporal stroke, 13% a subcortical stroke, and 10% a frontal stroke. At the right hemisphere patients, 43% had medial area involvement, 20% had frontal involvement, 19% had temporal involvement, and 18% had subcortical involvement. 69% of cerebellar strokes had peripheral cortical localization, originating from the heart. After the stroke, the majority of patients underwent some type of intervention (n=27).

Table 1
Physical characteristics of the participants

	ROB+VR (n=10)		ROB+FIZ (n=10)		CON (n=10)		All (n=30)	
	Mean	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**
Age (y)	65.5	5.16	65	7.34	68.5	4.92	66.3	1.33
Height (cm)	176	7.65	172.7	4.29	172	3.29	173.5	3.15
Weight before (kg)	71	9.95	74.8	7.14	69.4	8.79	53.8	4.46
Weight after (kg)	65.2	5.3	72.8	6.28	70.9	2.55	69.6	2.83

2.3 Results

The primary and the secondary outcomes were measured before and after the intervention, respectively. Measurements were recorded by the same person at both times. The interval between the two measurements was 3 weeks. The primary measurement was taken just before the exercise program, but for the group that received also robotic early mobilization therapy, it was taken on the 7th day after the exercise program, but also before the exercise program. The secondary measurement was performed after the 3-week movement program for all the three groups. Before starting the intervention phase of the research, all participants were given a survey, which included the tests detailed in the followings.

The results were measured before and after the 3-week program The primary outcome measure used was the modified Rankin Scale (mRS) [28] which indicates the severity of disability in daily activities and measures the degree of independence of the individual. The secondary outcomes were measured by the EuroQoL 5 dimensions questionnaire 5 levels version (EQ-5D-5L) [29], which has already seen a wide adoption [30], the Berg Balance Scale (BBS) [31], the Barthel Index (BI) [32] and the 6-minute walking test (6mWT) [33]. The EuroQoL 5 dimensions questionnaire (EQ-5D-5L) was chosen as the quality of life instrument due to its broad applicability across various conditions and its validated use in neurological rehabilitation settings. While disease-specific instruments, such as the Stroke Impact Scale (SIS), could provide more targeted insights, the EQ-5D-5L was preferred for its comprehensiveness and comparability with other studies addressing health-related quality of life. This allows for a more standardized evaluation of rehabilitation outcomes.

2.3.1 Primary Outcomes

To measure primary outcomes, we used the modified Rankin Scale (mRS) which measures the severity of disability at daily activities, and measures the degree of independence of the individual. The assessment took into account both physical and mental performance, and the combined scores of these were then used to give the test score. The advantage of the oral interview is that it also reveals signs of intellectual deficiencies and aphasia, which are also important considerations in the assessment. The scoring scale is as follows:

- **0** No symptoms
- **1** No significant disability
- **2** Mild disability… Able to care for themselves without assistance, but unable to perform all previous activities
- **3** Moderate disability... Requires some assistance for activities of daily life, but can walk without assistance
- **4** Moderately severe disability… Unassisted, unable to meet their own physical needs, unable to walk without assistance
- **5** Severe disability… Bedridden, incontinent, requires constant nursing care
- **6** Dead… A change of 1 unit in the mRS is considered clinically significant

2.3.2 Secondary Results

To measure functional ability, we used the Barthel Index (BI), which gives an overall picture of the patient's self-care and the obstacles they face in everyday life. Important aspects of the questionnaire include eating, transfer, personal toileting (toilet use, bathing), dressing, bowel and urinary movements, and walking up and down on flat floors and stairs. During the scoring process, the scores of each item are added together and the resulting total score will represent the BI score on a scale from 0 to 100, where the higher the score, the greater the autonomy.

The 5-level version of the EuroQol 5-dimensional questionnaire (EQ-5D-5L) was used to assess health-related quality of life. This test consists of a visual analogue scale (VAS) and a descriptive system covering 5 dimensions: 1 - Mobility; 2 - Self-care; 3 - Activities of daily life; 4 - Pain/well-being; 5 - Anxiety/depression. These grades can be assigned a number from 1 to 5 and the resulting numbers can be converted into a five-digit code that will give us the score for the whole questionnaire. The index score obtained from the questionnaire will indicate the level of health and related quality of life of the person. The lower this value, the better the health status In the second part of the test, the EQ VAS scale was used, with a range of 0-100 where 0 was the worst, and 100, the best imaginable health.

To measure balance (static and dynamic), we used the Berg-Balance test (BBS), which measures the subject's ability to maintain own stability safely both statically and dynamically during a predefined task sequence. The highest possible score was 56, representing perfect functional balancing ability. Below 45, the risk of falling increases significantly, the lower the score is, the higher the risk is.

The last test we used was the 6-minute walk test (6mWT) where we measured stamina and walking speed. The patient had to walk back and forth along a pre-designated 50 m long straight line on a flat surface for 6 minutes.

2.4 Interventions

An important aspect of our research was to assess the effectiveness of robot-assisted early mobilization, which was started on days 2-4 after stroke using a pre-designed exercise program. The program was basically based on the main prophylaxis guidelines (decubitus, contracture, thromboembolism). The steps of the early mobilization protocol were complemented in our study with robotic therapy to assist movement. Our early mobilization program was designed by taking the professional guidelines into account. The groups were formed for the study as follows: a control group (CON), a robot-assisted early mobilization + virtual reality therapy (ROB+VR) group, and a robot-assisted early mobilization + conventional physiotherapy (ROB+FIZ) group. The participants were divided into three same-size groups, 10 persons/group (n=30 persons). After that, they all participated in an exercise program, with different tasks of the program for each group, but with the same number of sessions (n=10 people per group, 1 session per day, 5 days per week for 3 weeks). One group made only the traditional physiotherapy exercise (control group), while the other two groups participated also in an early mobilization program with a robotic device. The difference between the two robotic therapy groups (ROB+VR and ROB+FIZ) was seen in the subsequent movement program where one group received VR therapy while the other group received conventional physiotherapy as treatment. The group sessions were always conducted by the same physiotherapist in all the three groups, in all cases in the hospital's neurorehabilitation gym. The sessions lasted approximately 50–60 minutes, which varied according to the patients' current condition. The exercise program lasted for a total of 3 weeks, during which the patients participated 1 session per day, 5 times per week.

2.4.1 Early Mobilization

The robotic device applied was the Motomed mentioned above, of which both the lying and the sitting positions were used, adapting it to the patients' current condition. On the first few days, until the patients' trunk control and standing capacities had reached a level where they were able to support themselves independently in a chair, the over-bed type was used. The aim of the device was to increase muscle strength in the lower and upper limbs, to preserve and regain joint range of motion, and to prevent the development of abnormal postures or, if they had already developed, to reduce them. The early mobilization exercise program was performed once a day for 1 week with the selected patients, each session lasted approximately for 30 minutes. These 30 minute-sessions were roughly divided proportionally between the upper and lower limbs, but the specificities of each patient were taken into account and the more affected body-part was rotated more.

2.4.2 Virtual Therapy

A session for patients receiving virtual therapy was structured as follows: 5 minutes warm-up, 25 minutes training, 25 minutes VR and 5 minutes recovery. Part of the warm-up was mainly about enhancing circulation and initiating the workout. The patients performed various trunk and limb mobilization and strengthening exercises while walking and jogging, at first without and then with the use of the equipment. The primary focus of the training was on restoring motor function through coordination and balance exercises, postural correction exercises and general muscle strengthening. During the exercises, we also regularly changed the directions, surfaces, and altitudes. These changes can be very effective in improving both coordination and balance. We also varied the speed at which tasks had to be performed within and between tasks (slow/fast movement execution, length of pauses between tasks). The patients exercised in a variety of postures, but most of the exercises were done while walking or standing. One of the most important parts of the training was the development of the gait pattern which involved stabilizing exercises and different step patterns using the given modifications and equipment. The difficulty of the exercises was adapted to the patients' load-ability and performance on the given day. The majority of the exercises consisted of complex and compound exercises. To implement VR therapy (also known as exergaming), we used Microsoft Xbox 360 and Xbox Kinect devices. These devices are able to sense and capture the shape of the individual and then place them in a virtual space, as well as mimic the patient's specific movements. Three different programs were selected during the therapy: Kinect Adventure - Reflex Ridge, Kinect Adventure - Space Pop, and Just Dance. The combination of acoustic and visual stimuli is more effective in improving motor function, making this program an excellent choice for the rehabilitation of neurological patients. Patients' performance can also be monitored in this program since after each level the system scores the accuracy of the movements as well as the way the movements are linked into a continuum. The cool-down phase included light walking exercises combined with breathing exercises and a stretch designed to loosen up the larger muscle groups. During the implementation of VR therapy, no significant issues were reported by the participants related to the use of the VR equipment. However, recognizing that even healthy individuals may require an adjustment period when wearing a large device on the head, we ensured that each session began with a short orientation period to familiarize patients with the equipment. For participants who experienced initial discomfort, adjustments were made to the headset, and additional support was provided as needed. Safety during the sessions was a primary concern, particularly as many of the tasks in the game programs involve standing and balancing. To address this, all exercises were closely supervised by a physiotherapist, and safety harnesses or supports were used for patients with limited balance or mobility. Furthermore, each task was tailored to the individual's ability to ensure that exercises were both challenging and achievable. For example, participants with greater mobility limitations engaged in modified versions of the tasks, focusing on seated or supported movements, while those with higher functional capacity performed more complex tasks.

2.4.3 Conventional Physiotherapy

The control group (CON) received conventional physiotherapy funded by the state. This exercise program consisted of two 30-minute sessions, one group session and one individual session. During the group exercise session, exercises were mainly performed in a seated posture, at first without equipment and then with equipment (Pilate's ball, ball stick, weight ball) to mobilize and strengthen the trunk and the upper limbs. During the individual exercise session, the main focus was on restoring lower limbs' function, which was achieved by exercises to improve gait and balance. These developmental exercises were based on various weight transfers, directional and levelling movements (back and forth, side to side, diagonal movements, squats, steps) and coordination movements with the arms.

2.5 Statistical Analysis

In statistical analysis, data are expressed as ± SD. The data were processed using IBM Statistics 26.0 and Microsoft Office Excel 2016. The significance level was set at 5%. The distribution of the variables was checked using the Shapiro-Wilk test. The data were analyzed using descriptive statistics (mean, median, standard deviation, relative frequency) and multivariate statistical analyses ($\chi 2$-test, Spearmann's correlation, Mann-Whitney U test). The degree of the changes within the group was checked with a paired T-test or Wilcoxon test according to the results of the normality test.

3 Results

3.1 Effects of the Interventions

In our research, we examined the participants with the modified Rankin Scale (mRS), both before and after the intervention. In the ROB+VR group, we found a significant difference between the first and the second measurements; the value of the first measurement was significantly higher than the value of the second one (p<0.001). The value of the first measurement was also significantly higher in the measurements of the ROB+FIZ group (p=0.041), but no significant difference was found in the CON group. We also examined the degree of improvement between the groups, and it turned out that the ROB+VR group achieved the greatest positive improvement, the average value of the pre-measurement and post-measurement decreased by a total of 51.43%. The ROB+FIZ group showed a smaller percentage of improvement (29.03%), whereas the results of the control group improved even less (11.43%). The results of the mRS test are presented in the table below (Figure 1).

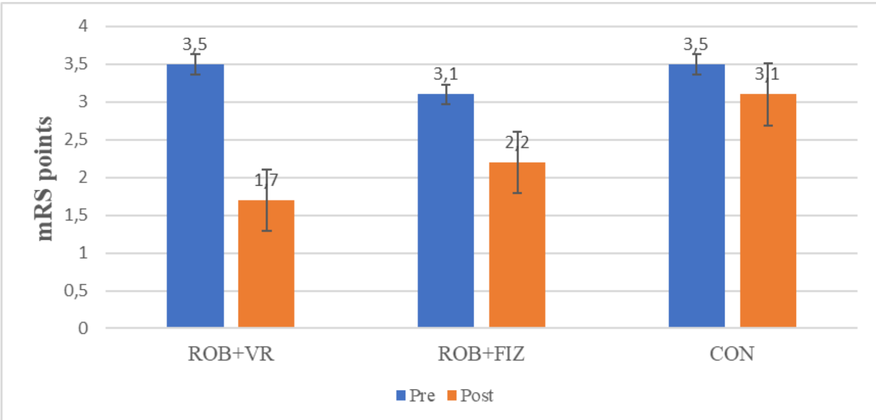

Figure 1

Comparison of mRS scores at the beginning and at the end of the interventions

Our next test was the Berg Balance scale (BBS). For all the three groups, paired t-tests were used to assess whether there was a significant difference between the averages of the two measurements. In each of the groups, the average of the first measurement was significantly lower compared to the second one: ROB+VR (p<0.001), ROB+FIZ (p=0.041), CON (p=0.046). Comparing the groups, it can be observed that the results of the ROB+VR group showed the greatest improvement (27.2%). The measurement results of the other two groups, ROB+FIZ (15.88%) and CON (12.33%), achieved a similar level of improvement.

The two measurements of the 6-minute walk test were also compared for all the three groups. Based on the paired t-test, it was found that the average value of the first measurement was also significantly lower for this group than the average value of the second (p=0.012). In the case of the control group (CON), the average value of the first measurement was 146.3±23.02, while the average value of the second one was 192.00±32.93. Similarly, to the results of the previous two groups, we also found here using a paired t-test that the average of the values of the first measurement was significantly lower than the average of the second one (p<0.001). In this test, we also examined the percentage of change between the two measurements in each group, and the following results were obtained: the ROB+VR group achieved the greatest improvement, followed by the ROB+FIZ group, and finally the control group achieved the least development. The ROB+VR group achieved a total of 94.58% higher results in the post-intervention measurement, which means a difference of 132.7 meters between the average values of the two measurements. The ROB+FIZ group, similarly to the other intervention group, also improved in a larger percentage (48.04%; 86 m) compared to the control group, which only improved by 31.24% (45.7 m). Based on this, it can be seen that the members of the ROB+FIZ and CON groups together did not achieve the same degree of improvement as the members of the ROB+VR group. It is interesting because the average value of the results of the ROB+FIZ group was the highest at the first measurement (179±64.19 m), while the average of the other two groups was similar (ROB+VR: 140.3±27.98 m; CON: 146.3±23.02 m). The table below shows the result of the 6-minute walking test.

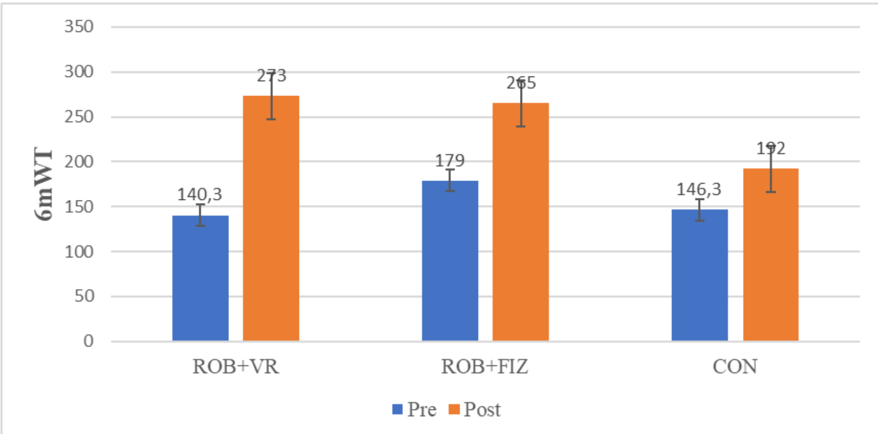

Figure 2
Pre- and post-measurement results of the 6-minute walking test

We also compared the results of the EQ-5D-QL tests for all the three groups, both before and after the interventions. After the second measurement, it can be observed that there was a significant difference between the two measurements, the ROB+VR and ROB+FIZ groups also showed improvement. The ROB+VR group achieved a greater improvement in depression (42.86%) than the ROB+FIZ (21.74%), but here the control group also improved significantly (41.67%). In this part, the ROB+FIZ group made the biggest improvement, their second measurement results improved by a total of 68.75%. Among the other two groups, ROB+VR also achieved a significant improvement (45.00%), but the control group not only did not improve, but even worsened compared to the first measurement.

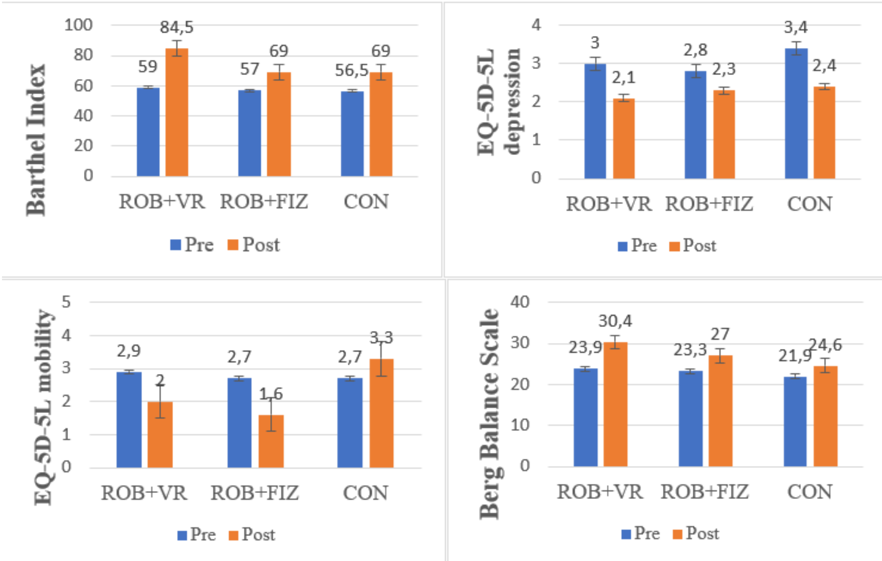

Figure 3

Comparison of EQ-5D-5L scores, BI scores and BBS scores at the beginning and at the end of the interventions

The three groups were also examined based on the Barthel index (BI) before and after the interventions. At all the three groups, we found a significant difference between the two measurements. The average value of the first measurement of the ROB+VR group was significantly lower than the average value of the second one (p=0.005). At the first measurement of the ROB+FIZ group, the average value was also significantly lower than the average at the second one (p=0.006). The average of the first measurement of the CON group was also significantly lower compared to the average value of the second one (p=0.004), similarly to the previous two groups. In the first measurements, it can be seen that all the three groups started at almost the same level, but we could observe that the ROB+VR group achieved the greatest improvement (30.18%). There is no significant difference between the ROB+FIZ (17.39%) and CON (18.12%) groups, a similar average score can be observed in both the first and second measurements, so the improvement in these two groups is almost the same. The findings of this study align with previous research indicating that intensive rehabilitation, including robotic and virtual reality therapies, can lead to measurable improvements in motor function and quality of life for stroke patients. However, it should be noted that the small sample size (10 patients per group) limits the generalizability of these results and may have contributed to the lack of statistically significant differences between the groups in some outcomes. Similar studies in larger cohorts, such as [35] [36], have demonstrated more robust intergroup differences, suggesting that larger sample sizes are crucial for detecting these nuances.

The consistent improvements observed across all groups, particularly in the ROB+VR group, highlight the potential strength of combining robotic and virtual reality therapies in early stroke rehabilitation. Future research should further investigate these therapies in larger-scale trials to validate these findings and explore the mechanisms underlying these effects. Despite the possibility that the potential role of spontaneous recovery, given the inclusion of relatively well-functioning patients, should be carefully considered when interpreting the results.

4 Discussion

In the present study, we compared various, still quite new, therapeutic treatments: the robotic early mobilization device treatment and the virtual reality therapy. We also examined their efficacies compared to the traditional physiotherapy treatments. Acute and subacute ischemic stroke patients who met the exclusion criteria set by us and voluntarily agreed to participate in the research were selected. During the survey, we did not take into account the equal distribution between the sexes; the assignment to the study and also to the groups were completely randomized. The most important objective of our research was to determine the extent the integration of robotic and virtual therapy alongside traditional physiotherapy would increase the effectiveness of post-stroke rehabilitation in terms of both quality of life and motor functions. In our study, we were able to successfully verify almost all of the pre-specified hypotheses with the help of our exercise program and the results of the standardized tests used for it. The motor function tests (6mWT, BBS) and the quality-of-life questionnaires (BI, EQ-5D-QL) for all the three groups similarly showed that the majority of the patients in our research had some kind of positive change in their quality of life. This means that our study intervention managed to produce an effect, thanks to which the participants perceived an improvement in their health status and were able to carry out their daily activities noticeably more efficiently. The reason for this is that as a result of the therapy, their need for help decreased (their degree of disability decreased), which also contributed to the fact that their endurance, ability to walk, stability, and balance increased. The results of our research tests revealed that the two groups which received early mobilization with a robotic device before the movement program showed the greatest improvement. The results of the ROB+VR group increased significantly as the evaluation of almost all the tests indicated, and this group showed the greatest improvement. The ROB+VR group showed the most significant improvement after the intervention during the 6-minute walking test where the average value of the second measurement almost doubled compared to the first one. Despite the promising results observed with advanced technologies such as robotic and VR therapies, it is important to underscore the central role of individualized physiotherapy in rehabilitation. Personalized treatment plans, tailored to the unique needs and capacities of each patient, remain the cornerstone of effective rehabilitation. Advanced technologies should be viewed as complementary tools that enhance, rather than replace, the foundational principles of individualized physiotherapy. Despite the promising results observed with advanced technologies such as robotic and VR therapies, it is important to underscore the central role of individualized physiotherapy in rehabilitation. Personalized treatment plans, tailored to the unique needs and capacities of each patient, remain the cornerstone of effective rehabilitation. Advanced technologies should be viewed as complementary tools that enhance, rather than replace, the foundational principles of individualized physiotherapy. Both the robotic early mobilization and the traditional physiotherapy groups (ROB+FIZ) achieved positive results in most measurements, and in several of our tests we found a significant difference between the pre- and post-measurement results. Among the results of the ROB+FIZ group, the most significant improvement was shown during the 6-minute walking test where the number of steps taken during the given time increased by 48%, similar to the other robotic treatment group. It was interesting at this measurement that during the first measurement before the start of the exercise program, the results of the ROB+FIZ group were also the highest, this group had the most steps taken during the 6 minutes. Based on our present research, the probable cause of these results may be the early mobilization that was performed before the start of the exercise program. During that one week, the movement performed with the robotic device greatly helped the participants to perform regular physical activity even before the movement therapy. This advantage can also be seen in the statistical analysis, and the results of the ROB+VR and ROB+FIZ groups show significantly more differences than the control group. In our study, only one group received this type of therapy, however, based on the results, this group achieved the most significant improvement in most tests. Our most outstanding result occurred during the 6-minute walking test where the ROB+VR group performed 94.5% better during the second measurement than during the first one. The number of steps taken within the given time increased significantly in this group, which allows us to conclude that virtual therapy significantly improves endurance and general muscle strength. As a result of these, the gait will also improve, the walking speed will also be faster, and the dynamic balance will also improve significantly [34]. While the VR therapy group demonstrated improvements in balance and coordination, suggesting a potential reduction in fall risk, this conclusion should be approached cautiously due to the limited sample size and the lack of long-term follow-up data. Research with larger cohorts and longer observation periods is needed to confirm these findings. The other important effect of the virtual therapy on quality of life was that the participants of the ROB+VR group reported a much better state of health at the time of the second measurement than at the time of the first one. The degree of disability and independence has also decreased significantly. In order to the virtual therapy can function properly, the related neurorehabilitation training is essential. In our research, the ROB+VR group performed an exercise program with neurorehabilitation and physiotherapy foundations since it is difficult to separate these two. The results of the group showed the greatest improvement among the three groups, probably as a result of this two-part, slightly more complex treatment. Another possible reason for the significant improvement was the intensity of the exercise program since this group attended treatments daily, 5 times a week for 3 weeks where one session lasted approximately 60 minutes. This program is therefore extremely intensive, during which it is possible to achieve better results much sooner and to detect such a large improvement within such a short time [35].

The basis of this exercise program is supported by studies, according to which in post-stroke rehabilitation 3-5 days/week of aerobic training (20-40 minutes, moderate intensity) and 2-3 days of resistance training (1-3 sets, 8-15 maximum repetitions) is the recommended exercise program [36]. We have already mentioned the significant improvements of ROB+FIZ in most of the tests above, but it is also important to note about the control group that, if not yet significantly, in many cases they showed improvement in the same way. From these results, it can be shown that traditional physiotherapy is still an effective rehabilitation treatment and has a place among therapies.

It is important to remember that one of the basic rules of rehabilitation treatment is that the treatments should be as complex as possible, so that the patient receives as many stimuli as possible. This will advance the entire healing process and ensure the effectiveness of the rehabilitation. Our present research also tried to support this, that the more varied a specific therapy program is, the more likely that the patient will achieve a perceptibly greater improvement in a proportionally less time.

Conclusions

Nowadays, it is particularly important to constantly compare traditional therapeutic methods with current and modern treatment options, in the hope that rehabilitation can be as complete as possible, and thus, as effective as possible. In today's world, robot therapy has begun to expand significantly, and correspondingly, many new opportunities are opening within our professional field as well. In the case of virtual therapy, at the next level, for example, different VR glasses and spaces created by artificial intelligence might be included, which could possibly be used to improve coordination and spatial orientation. In robotic therapy, more and more treatment options are available, such as exoskeletons, which can be used to re-teach physiological and harmonious walking. There are many robotic devices that can restore fine motor deficits or help regain trunk control and stability with various programs.

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