Journal of Clinical Neuroscience 120 (2024) 129–137

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.journals.elsevier.com/journal-of-clinical-neuroscience

Original Research

Effects of robotic-assisted gait training on physical capacity, and quality of life among chronic stroke patients: A randomized controlled study

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ARTICLE INFO

Keywords:
Stroke
Robotic rehabilitation
Functional independence
Functional capacity
Quality of life

ABSTRACT

Background: Even though robotic therapy is becoming more commonly used in research protocols for lower limb stroke rehabilitation, there still is a significant gap between research evidence and its use in clinical practice. Therefore, the present study was designed assuming that the wearable mobile gait device training for chronic stroke patients might have different effects on functional independence when compared to training with a stationary gait device. The present study aims to examine the effects of gait training with ExoAthlet exoskeleton and Lokomat Free-D on functional independence, functional capacity, and quality of life in chronic stroke patients.

Methods: The present study included 32 chronic stroke patients. Participants were randomly divided into two groups. Functional independence of patients was evaluated by using Functional Independence Measure (FIM), physical function was assessed by using the 30-second chair stand test (30-CST), functional capacity was measured by using the 6-Minute Walk Test (6MWT), and quality of life was assessed by using Short Form 36 (SF36). All participants underwent a conventional physiotherapy program for eight weeks, three sessions per week, and each session lasted 60 min. After the physiotherapy program, one group received gait training by using ExoAthlet exoskeleton (ExoAtlet 1 model/2019, Russia), while the other group received training by using Lokomat Free-D (Hocoma, Lokomat Pro Free-D model/2015, Switzerland). Participants were assessed at baseline and post-intervention.

Results: Results achieved in this study revealed that there was a statistically significant difference between FIM, 30-CST, 6MWT, and SF36 scores before and after the treatment in both groups ($p < 0.05$).There was no difference in FIM, 30-CST, and 6MWT results between Exoskeleton ExoAthlet and Lokomat Free-D groups ($p > 0.05$). However, there was a statistically significant difference between Exoskeleton ExoAthlet and Lokomat Free-D groups in terms of SF-36 sub-parameters "vitality", "mental health", "bodily pain", and "general health perception" ($p < 0.05$).

Conclusions: This study demonstrated that the use of ExoAthlet exoskeleton and Lokomat Free-D in addition to conventional physiotherapy, was effective in improving functional independence, physical function, functional capacity, and quality of life among chronic stroke patients. Incorporation of robotic gait aids into rehabilitation for chronic stroke patients might offer significant advantages.

1. Introduction

Stroke is defined as a condition that develops due to a disturbance in brain functions, either in a specific location or in the whole brain, rapidly manifests symptoms, and these symptoms persist for one day or longer, or result in death [1]. Motor functions are affected in 65 % of chronic stroke patients, and the majority of these patients experience a reduced level of functional independence [2]. It is believed that the most prominent challenges faced by chronic stroke patients are the distance walked in 6 min and the decrease in functional capacity [3]. In addition, cohort studies also reported that 22 % of chronic stroke patients did not regain any walking function [4].

A significant portion of chronic stroke patients suffer not only from physical disability but also from cognitive and emotional disorders [5]. General predictors of the poor quality of life after a stroke were reported to include medical comorbidities, loss of physical function, social role

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https://doi.org/10.1016/j.jocn.2024.01.010
Received 3 August 2023; Accepted 8 January 2024
Available online 18 January 2024

difficulties, emotional involvement, and depression [6–8].

In recent years, robotic technology has exhibited notable advancement thanks to faster and more powerful computers, innovative computational methodologies, and a broader range of electromechanical components. This technological advancement also made robotics suitable for rehabilitation interventions, and robotic rehabilitation is a promising method for treating patients with motor disorders. Its significance lies in its the potential to increase and carefully control the dosage of therapy [9,10]. However, robotic rehabilitation does not solely focus on augmenting the quantity and intensity of treatment.

Robotic systems not only generate simple and repetitive stereotypical movement patterns but can also be utilized in order to provide patients with more intricate and controlled multisensory stimuli [11]. It can be seen that the effect of rehabilitation technology on functional outcomes can be optimized by affording the nervous system greater opportunities to experience genuine activity-related sensorimotor input [12]. Nevertheless, there are ongoing studies examining the therapeutic effectiveness of robotic rehabilitation. In clinical rehabilitation practices addressing chronic stroke patients, robotic technologies are employed for gait training, providing opportunities to move freely on a stationary or mobile basis. Robotic devices are utilized as assistive, rehabilitative, and augmentative instruments in lower extremity rehabilitation for neurological conditions [13]. Considering the lower extremity rehabilitation, the Lokomat, utilized as a stationary device, was demonstrated to be effective in improving walking quality, speed, and balance in conditions such as Multiple Sclerosis, Cerebral Palsy, Parkinson's disease, Brown-Sequard syndrome, and vascular dementia [14]. Moreover, Lokomat was also reported to be an effective approach used in the rehabilitation of chronic stroke patients. In the literature, a retrospective case-control study examined the efficacy of Lokomat Free-D on functional independence, functional capacity, and balance in chronic stroke patients [15]. It was also reported that Lokomat Free-D is effective in chronic stroke individuals, not only affecting motor functions such as walking, balance, muscle strength, walking ability, and speed but also cognitive and emotional status. [14]. However, to the best of our knowledge, there is no study examining the effectiveness of Lokomat on the quality of life in chronic stroke individuals could be found. Another method utilized for lower extremity rehabilitation is the use of mobile gait devices. Devices such as MIRAD, XoR, and ExoAthlet exoskeleton are some of them [13]. The ExoAthlet exoskeleton was found to increase gait speed and stability, as well as reducing body sway, in conditions such as Multiple Sclerosis and spinal cord injuries [16,17]. In a randomized controlled study comparing ExoAthlet exoskeleton and traditional physiotherapy in chronic stroke patients, the ExoAthlet exoskeleton group exhibited significant improvements when compared to the traditional physiotherapy group. The ExoAthlet exoskeleton group had a decrease in hemiparesis severity, an increase in paretic limb muscle strength, improvement in balance, and notable enhancements in the walking process and speed [18]. However, there is no study available that examines the effectiveness of the ExoAthlet exoskeleton on quality of life in chronic stroke patients. In both literature and clinical practice, there are gaps concerning the effectiveness of Lokomat Free-D and ExoAthlet exoskeleton on different parameters. There is no study available that has comparing these two different methods among chronic stroke patients. Finally, this study aims to examine the effects of gait training with the ExoAthlet exoskeleton and Lokomat Free-D on functional independence, functional capacity, and quality of life in chronic stroke patients, as well as to investigate whether there are any different effects.

2. Materials and methods

2.1. Study design and ethics

Study design: Randomized Controlled Study.

Ethics: The study protocol was approved by from the institutional ethics board of Üsküdar University's Non-Interventional Ethics Committee (Approval no = 61351342/February 2021-66/26.02.2021). The present study was carried out in accordance with the principles outlined in the Declaration of Helsinki. Participants, who voluntarily agreed to participate in this study, signed a written consent form. The paper is registered with ClinicalTrials.gov, and the clinical trial number for this study is NCT05937464. This manuscript conforms to the CONSORT guidelines.

2.2. Sample size calculation

Sample size calculations were conducted using G*Power Version 3.1.9.4, utilizing the simple random sampling method. The sample size was calculated by taking the study of 'Does robot-assisted gait training improve mobility, activities of daily living and quality of life in stroke?' as a reference [19]. According to this study, 16 patients in each group planned to be included in the study were 85 % power (in studies, values of 0.70 and above are predicted to be valid and 0.80 to be quite sufficient). In the present study, it was determined that the effect size level was 0.42. (0.10 is expressed as a small, 0.30 medium, and 0.40 large effect size). It was determined that at least 16 patients were required to be included in each group, equally, and the groups were determined accordingly. The study was completed with a total of 32 patients.

2.3. Participants

This study was designed to include individuals aged between 18 and 65 years, who had experienced a stroke at least three months ago, were independently ambulatory, and were seeking treatment at a private rehabilitation center. However, individuals with certain medical conditions, including heart failure and rhythm disorders, visual and cognitive problems, neglect phenomenon, cerebellar pathology, any lower extremity surgery, and any other neurological pathology that could hinder their ability to undergo a training program, were excluded from the study.

Participants were randomized into two groups, with 16 individuals in each group: one group using the exoskeleton ExoAtlet, and the other using the Lokomat Free-D. The division was done using the block randomization method. Equal and random distribution of the sample group to the study groups was performed by using the closed/sealed envelope method. After evaluating the participants by making use of specific parameters, they were involved in the rehabilitation program, which consisted of sessions conducted three days a week, with each session lasting 60 min, for a total of eight weeks. Following the completion of the eight-week intervention, the participants were reassessed for evaluation parameters in the post-intervention phase. Assessments and interventions were administered under the guidance of an experienced physical therapist.

2.4. Evaluation methods

After collecting the demographic information, including age (in years), weight (in kilograms), height (in centimeters), body mass index (BMI in kg/m^2), gender, stroke type, and treatment history, the participants underwent evaluation based on the following parameters. Functional Independence Measure, Physical Functionality, Functional Capacity Assessments are determined as primary measure of this study. The Quality of Life Assessment was determined as a secondary measure outcome.

Functional Independence Measure: The participants' functional independence was assessed using the Turkish version of the Functional Independence Measure (FIM) [20]. The FIM is a tool that measures the degree of an individual's independence in basic physical and cognitive activities in their daily life. It consists of 18 questions and examines two main parameters: 1) Motor functions and 2) Cognitive functions. Each item is scored on a scale of 1 to 7, with 'level 1' indicating full dependence and 'level 7′ indicating complete independence. The total FIM score ranges between 18 and 126 points, with higher scores indicating a higher level of independence. The FIM is widely preferred and utilized as an activity scale in the field of rehabilitation. The ICC value of FIM is 0.90.

Physical Functionality Assessment: The physical functionality of the participants was evaluated by using the 30-Second Chair Stand Test (30-CST) [21]. The 30-CST is a valid and reliable assessment tool for chronic stroke patients (ICC = 0.94). The 30-CST is designed to assess lower body strength and endurance. Participants were instructed to sit in a standard-height chair (with a seat height of 43 cm) with their arms crossed over their chest. They were then asked to stand up fully and sit down again as many times as possible within a duration of 30 s. In order to decrease the effect of learning, all tests began with three to five practices.

Functional Capacity Assessment: The functional capacities of the participants were assessed by using the 6-Minute Walk Test (6MWT), which provides a single measurement to determine the functional capacity of individuals, particularly those having neurological diseases [22]. The 6-minute walk test (6MWT) is a reliable assessment method used for patients with stroke (ICC = 0.83) [23]. In the present study, a 30 m long straight line was divided into 3 m intervals and the total distance walked at the end of 6 min was calculated. The resting period of 10 min was given before the test. The importance of the distance to be walked was explained to the individuals participating in the present study and they were asked to walk as fast as they could without running. At the end of the test, the distance that the individuals could walk was recorded in meters (m).

Quality of Life Assessment: The quality of life of the participants was evaluated with the Turkish version of the Medical Outcomes 36-Item Short Form Health Survey (SF-36) scale [24]. SF-36 is a 36-item self-assessment scale consisting of eight sub-parameters. This scale consists of Physical functioning, Role limitations: Physical/Emotional, Social functioning, Mental health, Vitality, and General Health Perception sub-parameters. Each subscale is scored between 0 and 100 points. An increase in the score indicates an improvement in the quality of life. The SF-36 is an assessment method suitable for stroke patients (Cronbach alpha >0.7).

2.5. Rehabilitation protocol

After the routine physiotherapy and rehabilitation program, gait exercise training was conducted with the chronic stroke patients in both groups three days a week, 60 min each session, for eight weeks. Lasting 30 min, the routine physiotherapy and rehabilitation program included positioning, range of motion exercises, balance coordination exercises, strengthening exercises, and electrical stimulation to the quadriceps and tibialis anterior muscles. Gait exercise training was given to one group by using the exoskeleton ExoAthlet (ExoAtlet 1/2019, Russia) and to the second group by using the Lokomat Free-D (Hocoma, Lokomat Pro Free-D/2015, Switzerland) for 30 min. A 60-minute rehabilitation protocol was administered to all participants three days a week for a duration of eight weeks.

In addition to the routine physiotherapy program, gait training with a wearable gait device (ExoAthlet brand ExoAtlet 1 model/2019, Russia) was administered for 30 min to patients with hemiparesis in the Exoskeleton ExoAthlet group (Fig. 1) [25].

The ExoAthlet (ExoAtlet 1 model/2019, Russia) weighs 23 kg, including the battery, and supports its own weight by transferring it to the ground through the footplates. It is attached to the wearer at five main locations: footplate, shin, thigh, pelvis, and torso. The lengths of the shin, thigh, and foot segments, as well as the width of the pelvis, can be adjusted to accommodate different subject heights (weight up to 100 kg and height between 1.55 and 1.95 m). The footplates are made of carbon fiber to accommodate human feet, enabling a single degree of freedom (ankle dorsiflexion/plantar flexion) to act as a passive spring

Fig. 1. Gait Training with the Exoskeleton ExoAtlet.

with a specific stiffness (150 Nm/rad). The control of the ExoAtlet is initiated and managed by using a PC tablet or a "smart crutch" for experienced users [17]. Exoskeleton ExoAthlete was worn in a sitting position on a bench that was adjusted individually, in a way that would not allow compensatory movements such as pelvic elevation and hip circumduction. Then, the participant was instructed to stand up, walk while counting, and proceed to the gait training. Since the Exoskeleton ExoAthlet device does not have a weight-supporting system, the participant engaged in the training using their own body weight. The therapist supported weight transfer with the handles on the back of the device. The program was planned for 30 min, 3 days a week, with each session excluding the dressing and removing times. Gait training was conducted in the following manner: a warm-up gait in low-speed mode for 5 min at the beginning, followed by walking in medium-speed mode with correct kinetics and kinematics in the appropriate walking pattern for 20 min, and finally a 5-minute cooling down period involved walking in low-speed mode. During the gait exercise training, the speed level and stepping mode were set to the midrange mode.

The Lokomat (Hocoma, Lokomat Pro Free-D model/2015) is a robotic device consisting of motorized gait orthosis with linear computer-controlled actuators integrated into each hip and knee joint, body weight support (BWS), and a treadmill [15]. In addition to the conventional physiotherapy program, patients in the Lokomat Free-D group received gait training with a stationary gait device (Hocoma, Lokomat Pro Free-D model/2015, Switzerland) for 30 min (Fig. 2) [15]. The program was scheduled for 3 days a week, with each session lasting 30 min, excluding the wearing and removal times. In the device, adjustments were made for symmetrical weight bearing, facilitation of dorsiflexor muscles, adequate hip flexion, and knee flexion to enable the patient to bear full weight. Moreover, movements such as pelvic elevation and hip circumduction were restricted in order to ensure a normal gait pattern adaptation. The gait exercise training consisted of a

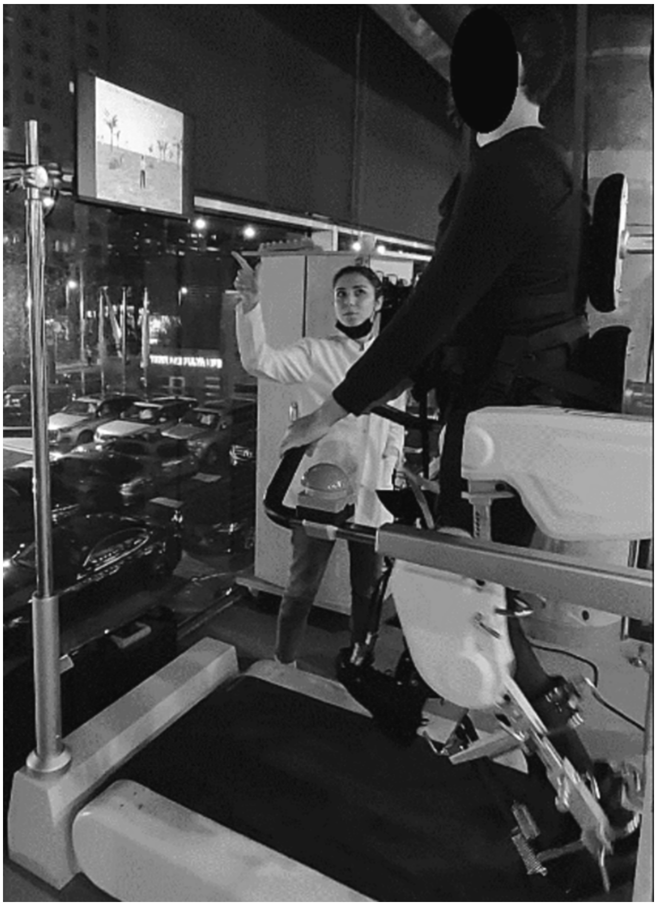

Fig. 2. Gait Training with the Lokomat Free-D.

5-minute warm-up walking at 1.2 km/h (low speed) at the beginning, followed by 20 min of walking at 2.4 km/h (moderate speed) in the correct walking pattern with proper kinetics and kinematics. Finally, a 5-minute cool-down gait was performed at 1.2 km/h. During the training, the physiotherapist ensured equal weight transfer by focusing on the initial contact and loading response of the affected extremity. The support system provided 50 % body weight support for each participant. Additionally, feedback games were displayed on the screen in front of the patient to accompany the session.

2.6. Statistical analysis

Data analysis was performed by using SPSS for Windows 25.0 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) package program. Number and percentage for categorical variables, mean ± standard deviation or median, and minimum and maximum values were used for continuous variables. Normal distribution was tested by using the Kolmogorov-Smirnov test. Mann Whitney-*U* test, Fisher's exact Chi-square test, and Pearson Chi-square test were used when comparing two independent groups. The values obtained before and after the treatment were compared by using the Wilcoxon test in order to demonstrate the effectiveness of both device-assisted gait training. The effect size was calculated by Cohen's d analysis and the statistical significance level was set at $p < 0.05$.

3. Results

Initially, 40 **chronic** stroke patients were involved in the study, and 8 individuals did not meet the inclusion criteria. Thus, the study was completed with a total of 32 individuals. The flow chart of the study is presented in Fig. 3.

The sociodemographic characteristics of the **chronic** stroke patients included in the study are shown in Table 1.

The results of this study showed that there was a statistically significant difference between functional independence, functional capacity, and quality of life results before and after gait exercise training in both groups ($p < 0.05$) (Table 2).

As a result of this study, when comparing the patients who received gait training with Exoskeleton ExoAthlet in addition to conventional treatment and those who received gait training with Lokomat Free-D in addition to conventional treatment before and after the treatment, no significant difference was found in the FIM, 6DYT (6-Minute Walk Test), and 30-CST (30-Second Chair Stand Test) results ($p > 0.05$). The effect size between the groups showed that the Exoskeleton ExoAthlet gait training method had a lower level when compared to the Lokomat Free-D gait method in terms of FIM (Cohen's d: 0.39); it showed a low effect size for 6MWT (Cohen's d: 0.10), and a small effect size (Cohen's d: 0.24) for the 30-CST (Table 3).

As a result of this study, when comparing the pre-treatment and post-treatment SF-36 results of the patients, who received gait training with Exoskeleton ExoAthlet in addition to conventional treatment, and those who received gait training with Lokomat Free-D in addition to conventional treatment, it was found that there was a statistically significant difference between the groups in terms of the social functionality parameter scores before the treatment ($p < 0.05$). In addition, after the treatment, there was a statistically significant difference ($p < 0.05$) in the parameters of vitality, mental health, bodily pain, and general health perception. However, there was no significant difference between other parameters ($p > 0.05$). When examining the effect size between the groups, it was observed that there was a strong treatment effect with both Exoskeleton ExoAthlet and Lokomat Free-D on the parameters of physical function, energy/vitality, mental health, and general health perception (Cohen's d: 0.87, 0.83, 0.86, and 1.01). However, in the pain parameter, the Exoskeleton ExoAthlet gait training method showed a moderate treatment effect (Cohen's d: 0.65) when compared to the Lokomat Free-D gait training method. Although there was no difference in the treatment effect (Cohen-d: 0.19) between the two robotic-assisted gait training methods in the emotional role difficulty parameter, the therapy effect of s Exoskeleton ExoAthlet gait training method was lower (Cohen-d: 0.39) in comparison to the Lokomat Free-D gait training method in terms of the physical role difficulty and social functionality parameters (Table 4).

4. Discussion

Significant advancements have been achieved in robotic technology, especially in the last ten years, and the use of robotic technology in healthcare has increased. The use of robotic technology increased in post-stroke rehabilitation due to its advantages such as performing movements very similar to normal activity, providing continuous stimulation of the central nervous system, and creating treatment options with appropriate intensity and dosage for the patient during the rehabilitation process [26].

The results achieved in this study revealed an increase in functional independence, functional capacity, and quality of life in both groups of chronic stroke patients after an eight-week Exoskeleton ExoAtlet and Lokomat Free-D gait training program in addition to conventional physiotherapy. However, no significant differences were found in these parameters between the different robotic gait training approaches. In addition, it was concluded that patients, who received gait training with Exoskeleton ExoAtlet, experienced a more positive effect on sub-parameters of quality of life, including vitality, mental health, bodily pain, and general health perception.

In a study carried out by Schwartz et al., 6-week robot-assisted gait training implemented in addition to conventional treatment in patients with subacute stroke yielded significant improvements in independent

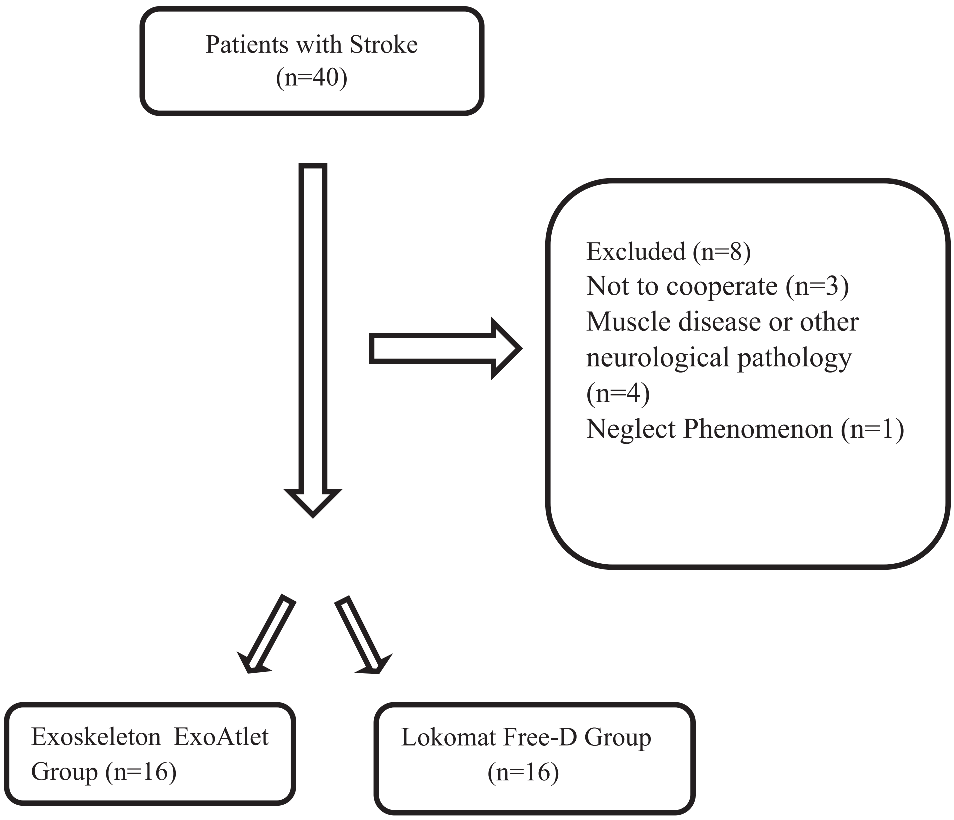

Fig. 3. Study flowchart.

Table 1
Sociodemographic Characteristics of Chronic Stroke Patients.

	Exoskeleton ExoAtlet Group (n = 16)	Lokomat Free-D Group (n = 16)	p
Age (Year) *(Mean ± SD)*	56.75±719	57.81±8.10	0.669[a]
Gender			
Female	8	7	1.00[b]
Male	8	9	
BMI (kg/m^2) *(Meant ± SD)*	27.22±3.41	26.07±2.80	0.341[a]
Etiology			
Ischemic	16	15	1.00[b]
Hemorrhagic	0	1	
Treatment *Yes/No*	16/0	15/1	1.00[c]
Time since stroke (months)	31.00±13.18	34.00±15.25	0.281[a]

(a: Mann Whitney U Test, b: Fisher's Chi-square Test, c: Pearson Chi-square Test, p < 0,05, BMI: Body Mass Index, SD: Standard Deviation).

walking and Functional Ambulation Category (FAC) Scale results [27]. In another study, it was concluded that robot-assisted gait training implemented in addition to conventional treatment with stroke patients was effective in increasing the functionality of patients, and it was shown that this effect continued in their two-year clinical follow-up [28]. The results of the same study revealed that the robotic-assisted training program, when applied in addition to conventional treatment, increased the aerobic capacity in subacute stroke patients. It also increased the functional independence level of deconditioned patients with cardiovascular regeneration, leading to increased functional capacity, which had positive effects on the functionality of these individuals. In a systematic review conducted by Mehrholz et al., it was stated that stroke patients, who received robotic-assisted gait training, were more likely to have independent ambulation in comparison to patients, who received neurophysiological approach-based gait training [29]. On the other hand, Choi et al. compared robot-assisted gait training with conventional physiotherapy in chronic stroke patients and found that patients, who received four-week robotic-assisted gait training, had a significant increase in the Functional Ambulation Category (FAC) Scale and Functional Reach Test results [30]. Studies carried out in the last ten years have emphasized the importance of combined therapy. Given the results of the present study, it was observed that there was an improvement in the Functional Independence Measure scores of the stroke patients, who received gait training with both Lokomat Free-D and Exoskeleton ExoAthlet. However, the groups were not superior to one another. In the study carried out by Mustafaoglu et al., the authors compared combined treatment, robot-assisted gait therapy, and conservative treatment on subacute stroke patients. The results of the combined treatment were found to be superior to the others in terms of both functional capacity and quality of life outcomes. In addition, it was shown that robot-assisted therapy solely was not more effective than other methods. This result was attributed to differences in treatment dosages [19]. In the present study, Exoskeleton ExoAthlet and Lokomat Free-D had the same treatment dosages. The reason why these two methods were not found to be superior to each other despite having the same therapy dosages is thought to be due to both methods were planned as combined approaches. In a randomized controlled study carried out by Aprile et al., improvements were observed in balance in both groups, which received "the combined method" and "the combined method with additional balance training". However, in the group that received balance training in addition to the combined method, there was a significant increase in lower extremity muscle strength and muscle tone. Furthermore, it was also found that trunk oscillations and displacement during dynamic exercises decreased more in this group. [31]. In the present study, both of the combined methods aimed to improve the gait and increase the functional independence level and capacity. Although there were no statistically significant differences

Table 2
The Results of Clinical Assessment of the Groups Before and After the Treatment.

Parameters	Exoskeleton ExoAtlet Group (n = 16)			Lokomat Free-D Group (n = 16)		
	BT	AT	p	BT	AT	p
FIM	82.50±16.50	93.50±18.54	0.006	79.43±16.43	88.62±15.78	0.000
6MWT	520.94±133.21	578.44±145.47	0.001	518.44±97.46	564.37±114.36	0.000
30-CST	7.87±2.62	10.37±2.24	0.001	7.38±2.65	9.81±2.40	0.002
SF-36						
Physical functioning	48.12±22.05	73.12±17.40	0.001	41.87±23.22	59.37±13.76	0.003
Role limitations: Physical	21.35±18.50	62.50±18.25	0.000	26.56±18.23	54.68±18.75	0.025
Role limitations: Emotional	25.00±28.54	62.50±29.50	0.002	31.25±17.45	56.25±15.94	0.006
Vitality	40.87±17.89	63.44±14.57	0.002	38.75±18.92	48.06±21.43	0.003
Mental health	46.37±20.97	65.75±16.45	0.002	40.81±13.43	52.81±13.22	0.001
Social functioning	50.40±25.35	65.62±17.38	0.000	64.06±13.59	72.66±13.85	0.001
Bodily Pain	47.50±17.67	68.59±20.73	0.001	43.90±17.74	56.41±16.48	0.001
General health perception	46.87±14.24	66.56±15.56	0.000	34.53±21.45	49.06±18.72	0.000

Wilcoxon test, p < 0,05, Functional Independence Measure (FIM), 6-Minute Walk Test (6MWT), 30-second chair stand test (30-CST), Standard Deviation (SD), Before Treatment (BT), After Treatment (AT).

Table 3
FIM, 6MWT, 30-CST comparison results between groups.

Assessment Parameters	Exoskeleton ExoAtlet Group (n = 16)Median (%25-%75)	Lokomat Free-D Group (n = 16) Median (%25-%75)	p	Cohen d
FIM Before Treatment After Treatment	77.5 (66–94.75)88 (76.5–106)	85 (73–94.5)92.5 (81.75–107)	0.539 0.445	0.18 0.39
6MWT Before Treatment After Treatment	527.5 (442.5–597.5)582.5 (457.5–682.5)	530 (410–617.5) 605 (436.25–687.5)	0.809 0.780	0.02 0.10
30-CST Before Treatment After Treatment	7.5 (5.25–9.75)10 (7.5–12)	8 (5.25–9.75)10 (9–11.75)	0.696 0.696	0.18 0.24

**: Mann Whitney U Test, p < 0,05, Functional Independence Measure (FIM), 6-Minute Walk Test (6MWT), 30-second chair stand test (30-CST).

between the two methods in terms of the evaluation parameters, these results suggest that both methods could offer advantages in the treatment protocols for chronic stroke patients.

Gait speed and distance of stroke patients decrease due to reasons such as reduced lung volumes, fatigue, decreased respiratory muscle strength, reduced aerobic capacity due to motor impairment, decreased effective contraction capacity of inspiratory muscles, decreased muscle strength, and decreased cardiorespiratory endurance [30,32]. Another result of this study was the increase in the 6-minute gait distance among chronic stroke patients in both groups. However, there was no statistically significant difference between the Exoskeleton ExoAthlet and Lokomat Free-D groups in this regard. Balance, transfer, and ambulation problems are among the most significant issues that restrict patients' independence in daily living activities, particularly due to the negative impact of neurological pathologies on the locomotor system. Therefore, improving the ambulation is the main goal of rehabilitation in most neurological cases [33]. In many previous studies investigating the effectiveness of robotic gait training, parameters such as gait speed were examined by using the 6MWT and the "Time Up and Go Test", and progress was observed in all of these parameters [34,35]. In the review carried out Selves et al., it was suggested that the 6-Minute Walk Test (6MWT) is the most reliable indicator for assessing gait performance in post-stroke rehabilitation [34]. In a study carried out by Pawłowski et al., assessment parameters such as the 6MWT and the Time Up and Go Test were used to investigate the effectiveness of the Lokomat in a group of 20 participants diagnosed with Cerebral Palsy. Their study results indicated that individuals with Cerebral Palsy had improved gait speed

Table 4
Comparison between quality of life results of the groups.

SF-36 parameters	Exoskeleton ExoAtlet Group (n = 16)Median (%25-%75)	Lokomat Free-D Group (n:16) Median (%25-%75)	p	Cohen d
Physical functioning Before Treatment After Treatment	45 (30–60)75 (56.25–90)	40 (22.5–55)60 (55–68.75)	0.402 0.051	0.27 0.87
Role limitations: Physical Before Treatment After Treatment	25 (0–33.33)62.5 (50–75)	12.5 (0–68.75)50 (50–75)	0.926 0.341	0.19 0.31
Role limitations: Emotional Before Treatment After Treatment	16.66 (0–58.33) 66.67 (66.67–66.67)	16.66 (0–66.75)50 (33.33–100)	0.780 0.590	0.93 0.19
Vitality Before Treatment After Treatment	39.5 (26.25–53.75) 60 (55–75)	37.5 (21.25–50)50 (28.75–60)	0.696 0.015*	0.46 0.83
Mental health Before Treatment After Treatment	49 (22–68)68 (60–76)	42 (29.75–54.5)60 (52–60)	0.468 0.010*	0.31 0.86
Social functioning Before Treatment After Treatment	50 (25–63.75) 68.75 (50–75)	62.5 (50–75)75 (62.5–84.37)	0.097 0.270	0.96 0.44
Bodily Pain Before Treatment After Treatment	45 (33.12–57.5) 67.5 (57.5–80)	45 (25.62–57.5)65 (45–65)	0.696 0.023*	0.20 0.65
General health perception Before Treatment After Treatment	50 (35–55)65 (60–80)	32.5 (17.5–52.5)50 (32.5–68.75)	0.094 0.008*	0.77 1.01

p**: Mann Whitney U Test, p < 0,05, Cohen d; 0.2: Small, 0.5: Medium, 0.8: Large, Short Form- 36 (SF-36).

and enhanced results of both the 6MWT and the Time Up and Go Test [35]. In this study, in addition to the 6-minute walk test, the 30-second sit-to-stand test was also used in evaluating the functional independence. Mcleod et al. used the 30-second sit-to-stand test to investigate the effectiveness of the Keego gait device in individuals with chronic stroke. The results achieved in their study suggest that participants showed an improvement in their 30-second sit-to-stand performance [21]. The results indicated that stroke patients, who received robot-assisted gait training in both groups, achieved an improvement in functional independence and functional capacity after an eight-week treatment program. However, there was no superiority observed between the groups in terms of these parameters. In the randomized controlled study carried out by Chang et al., where Lokomat was used to provide gait training to subacute stroke patients, the group that received robot-assisted gait training exhibited a significant increase in cardiorespiratory fitness level and lower extremity strength when compared to the control group [36]. In the randomized controlled study carried out by Dennis et al., which investigated the effectiveness of Exoskeleton ExoAthlet in subacute stroke patients, no significant differences were found in terms of gait function, balance, cognition, and quality of life when compared to the traditional method [37]. In contrast to these findings, it was determined in the randomized controlled study carried out by Kotov et al., which investigated the effectiveness of Exoskeleton ExoAthlet in chronic stroke patients, that the Exoskeleton ExoAthlet group had a decrease in the degree of hemiparesis, an increase in muscle strength in the paretic extremity, improvement in balance, and enhancements in gait processes and speed compared to the traditional method [18]. In the present study, Exoskeleton ExoAthlet yielded significant results within the group in terms of functional capacity, functional independence, and quality of life before and after treatment. As a result, it is considered that the present study supports the clinical use of Exoskeleton ExoAthlet in chronic stroke patients, in contrast to subacute stroke patients.

The results of this study showed that the functional independence and functional capacity of the stroke patients in both groups who received robot-assisted gait training increased after the eight-week treatment. However, there was no difference in these parameters between the groups. Between the groups, there was no difference in terms of effect size for functional independence and functional capacity parameters. However, there was a difference in the quality-of-life parameters, including vitality, mental health, bodily pain, and general health perception. These results show that combined therapy plays an important role in the treatment of stroke patients, similar to the literature. In addition, it is suggested that robotic-assisted gait training allows these individuals to be more mobile and ambulate more freely, and as a result, to develop functional capacity and functionality more. In this study, although the groups did not show statistically significant superiority to each other, the fact that both robot-assisted gait training methods enable gait training in accordance with normal gait biomechanics and share similar basic principles suggests that it offers an advantage for the patients in both groups. It was determined İn the present study, that both robot-assisted gait training, performed in addition to conventional physiotherapy, increased the gait speed and distance of stroke patients. Given the results achieved in the present study, there is a relationship between robot-assisted gait training and increasing patient motivation through visualized performance feedback, increasing cardiopulmonary endurance, respiratory capacity, and lower extremity muscle strength, positive effects on motor learning with repetitive training, and increasing gait speed and gait distance.

The number of studies on quality of life and rehabilitation treatments among individuals with chronic diseases such as stroke that restrict mobility is limited. It was reported that limitations in upper and lower extremity motor functions are associated with a decreased perception of quality of life, even in patients with a high recovery rate after stroke (Lai ve ark., 42 2002) [38]. It was determined that upper extremity robotic rehabilitation has positive effects on the quality of life in individuals with chronic stroke [39]. In a randomized controlled study carried out by Kutner et al. in subacute stroke patients, robotic-assisted therapy was performed in order to improve fine motor function, and the change in quality of life was evaluated. It was shown that the quality of life has increased positively in both the robot-assisted therapy group and the group that received robot-assisted therapy in addition to conventional treatment [40]. Taravati et al. reported that robotic technology has a positive effect on the emotional state and quality of life of patients undergoing upper extremity rehabilitation [41]. However, no study examining the effect of lower extremity robotic rehabilitation on the quality of life among chronic stroke patients could be found in the literature. The present study, in contrast to the existing literature, examined the effect of Lokomat Free-D and Exoskeleton ExoAtlet on the quality of life in chronic stroke patients during lower extremity rehabilitation. Both methods were compared in terms of functional independence, functional capacity, and quality of life. Both methods yielded results that improved the quality of life across all subparameters of the SF-36. In the randomized controlled study carried out by Dundar et al. on stroke patients, it was determined that Lokomat yielded improvement across all parameters of the SF-36 and was more effective in terms of quality of life when compared to traditional physiotherapy [42]. In the randomized controlled study carried out by Taveggia et al., which compared conservative gait training and training provided with the Lokomat, it was found that both forms of training were effective in improving gait performance. However, the robotic gait group achieved a higher level of increase in functional independence and quality of life [43]. In the present study, it was found that Exoskeleton ExoAtlet was more effective than Lokomat Free-D in terms of the subparameters of general health perception ($d = 1.01$), pain ($d = 0.65$), mental health ($d = 0.86$), and vitality ($d = 0.83$). This is believed to be related to the fact that patients, who receive gait training with the Exoskeleton ExoAthlet, feel more independent and freer in the device. Gait function can be influenced by various factors, including the technical specifications of the device used, the content of gait training, dosage, frequency, motivation, and any accompanying problems or conditions [44,45]. They can move freely to the desired area without being restricted to one point, contributing to their motivation on an individual level. In conclusion, robotic-assisted gait training is thought to have an important role in modern neurorehabilitation.

5. Limitations and future directions

The study has some limitations. The long-term effects of robotic-assisted gait training were not evaluated in this study. Additionally, different psychometric properties that would affect the quality of life were ignored. Future studies taking these parameters into consideration may provide different perspectives on the interpretation of results.

6. Conclusion

In conclusion, the results achieved in this study showed that gait training with Exoskeleton ExoAthlete and gait training with Lokomat Free-D for eight weeks administered in addition to conventional physiotherapy have positive effects on functional independence, functional capacity, and quality of life parameters in post-stroke patients. Training with Exoskeleton ExoAthlet had a more positive effect on the quality-of-life sub-parameters, such as vitality, mental health, bodily pain, and general health perception, when compared to gait training with Lokomat Free-D. These results suggest that both robot-assisted gait training methods can be preferred and implemented in the current physiotherapy and rehabilitation interventions for stroke patients.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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