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RESEARCH ARTICLE

EFFECT OF ASSISTIVE ROBOTIC TECHNOLOGIES ON QUALITY OF LIFE AND FUNCTIONAL INDEPENDENCE IN INDIVIDUALS WITH SPINAL CORD INJURY

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ABSTRACT

Purpose: To investigate the effect of assistive robotic technologies on quality of life, functional independence, and perceived fatigue level in individuals with spinal cord injury (SCI).
Material and Methods: This research involved a cohort of 25 patients who had been diagnosed with SCI. To assess their progress, clinical assessments were administered both at the commencement and completion of a six-week robotic rehabilitation treatment regimen. The evaluations encompassed the use of the Spinal Cord Independence Measure (SCIM III) to measure their performance in daily living activities and mobility. Additionally, the quality of life was assessed using the World Health Organization Quality of Life Scale – Short Form (WHOQOL-BREF) scale, while the levels of fatigue experienced during rehabilitation were gauged using the Modified Borg Scale (RPE).
Results: The participants' average age and BMI were 40.72±1.28 kg/m2 and 23.43±0.57 year. Statistically significant differences were found in self-care (p=0.006) and mobility (p=0.004) values of SCIM III scale compared to pretreatment values. WHOQOL-BREF General health status, Physical health, Psychological, Social relations and Environment sub-parameters all showed statistically significant differences compared to pre-treatment values (p<0.001). There was a significant decrease in the RPE value to determine the level of fatigue during exertion in robotic walking training (p<0.001).
Conclusion: Assisted robotic rehabilitation approaches increased individual independence, quality of life and reduced fatigue during exertion in Individuals with SCI. We think that assisted robotic approaches applied in addition to traditional rehabilitation provide additional benefits in increasing the level of independence and quality of life of individuals with SCI in daily life and reducing fatigue during exertion.

Keywords: daily living activities, robotic rehabilitation, spinal cord injury, quality of life.

INTRODUCTION

Spinal cord injury (SCI) often experiences a significant decrease in their quality of life (QoL) due to lack of voluntary muscle control, which severely affects their independence. After sustaining a SCI, individuals typically face an irreversible motor and sensory impairment, resulting in symptoms like spasticity, muscle paralysis, atrophy, pain, and gait disorders (1). SCI has profound consequences for the entire body, affecting systems such as the musculoskeletal, respiratory, cardiovascular, gastrointestinal, genitourinary, metabolic, skin, and neurologic systems (2).The SCI often prevents individuals from fulfilling their daily activities and may have a detrimental effect on their overall QoL (3). The QoL is closely linked to the fulfilment of personal needs, having control over one's neighborhood and having the freedom to choose. Research findings show while compared to the general population, individuals having SCI experience a significant decrease in their QoL (4). However, it is important to note that adjusting to living with severe impairment is a complex journey and life fulfilment trajectories may differ between various subgroups of individuals with SCI (5). To advance the field of rehabilitation, assistive technologies should focus on harnessing individuals' potential and promoting their social engagement and successful reintegration into society, ultimately enhancing their QoL.

Some of the innovations examined in these studies include neuro-prostheses, hybrid systems, orthotic devices, robotic aids, limb supports, virtual reality, virtual reality, reinforced exoskeletons, brain-computer interfaces, and portable devices for electronic assistive (6-11). This innovation hold promises for applications in aiding individuals in tasks, facilitating rehabilitation, mobility and enhancing brain connectivity. These studies have shed light on the effectiveness, adoption and perceived equity of using assistive technologies for behavioural management, diagnostic interventions and collaborative self-management among people with SCI (8, 9). Studies underline how the continued development and expanding use of these technologies offers an excellent opportunity to improve people with disabilities' QoL (6, 11). Furthermore, augmented exoskeletons and brain-computer interfaces demonstrated their utility and value as assistive technologies and educational interventions during the rehabilitation phase for individuals with disabilities resulting from quadriplegia. Nonetheless, particular challenges and areas requiring further work also come to the fore. There are limitations in the application of brain-computer interfaces, and a substantial knowledge gap exists concerning brain connectivity following SCI, which could significantly influence the selection of appropriate assistive technologies.

Robotic-assisted walking training was introduced at the end of the 1990s and provides a number of benefits (12). It allows you to increase the frequency and overall duration of training sessions while retaining the natural gait pattern. The practice of task-specific gaits enhances the sensory response related to typical movement and has the potential to induce changes in the relevant motor centres (13). The speed of movement, level of assistance and amount of weight support can be regulated to create a challenging environment for individuals to practice stepping. Robotic rehabilitation is recognized as potentially enabling SCI individuals to lead a healthier and more active gait and increase their physical activity levels, and is a promising approach for restoring functional gait and improving locomotor skills (14). After evaluating the literature in our country and other countries, we aimed to contribute to the rare studies conducted in Türkiye on robotic rehabilitation and traditional rehabilitation combined treatment. In addition, in our study that we conducted only with patients at certain levels of neurological injury, we aimed to minimize the effect of neurological differences between the levels of the patients on the treatment process. Similar studies conducted on specific levels in the future will allow us to gain more information about the symptoms and consequences of SCI depending on the levels. In our study, we planned to investigate the effect of the individual fatigue level that occurs during rehabilitation on robotic rehabilitation training. It appears that the number of studies conducted in this context is very limited. In line with the goals we set in our study, we aimed to analyze the effect of assistive robotic technologies on the health QoL, functional independence and perceived fatigue level in individuals with SCI.

MATERIAL AND METHODS

In this study, 25 individuals diagnosed with SCI participated. Our study is a single group and robotic rehabilitation, and traditional neurological rehabilitation were applied in the same process. When classifying spinal cord injuries, it is determined whether the injury is complete or incomplete and the American Spinal Cord Association Impairment Scale (AIS), which indicates the degree of impairment, is determined. This scale is a standardized neurological examination used by the rehabilitation team to assess the sensory and motor levels which were affected by

Table 1. Demographic information of the participants

Variables	Value Mean±SD or n (%)	
Age, Year	40.72±1.28	
Gender Male/Female	18 (%72)	7 (%28)
BMI (Kg/m^2)	23.43±0.57	
Duration of injury (Years)	2.60±1.66	
Neurological Level	T2	3 (12)
	T3	1 (4)
	T6	1 (4)
	T8	7 (28)
	T9	1(4)
	T10	1 (4)
	T12	11 (44)

BMI (Kg/m2): Body Mass Index, n: number of people, , SD: standard deviation, T: thoracic spine level

the spinal cord injury. Inclusion criteria: those diagnosed with spinal cord injury, thoracic (T1-T12) and lumbar (L1-L5) level injuries according to AIS were included in the study. Those with conditions that may prevent their participation in robotic rehabilitation (infection, incontinence, open wound in the lower extremity, etc.), additional orthopedic diseases and cognitive problems were excluded from the study.

Rehabilitation Program

A traditional rehabilitation programme aimed at increasing the functionality and general health levels of the patients during their inpatient treatment was applied; exercises were performed to increase general endurance and aerobic capacity, improve range of motion in the body and limbs, increase muscle strengthen and improve mobility. The standard exercise program performed here consists of stretching, strengthening, functionality, balance and coordination exercises performed on the meth. The aim was to improve functionality and mobility by selecting frequently used activities in daily life activities to solve the problems in the areas where the patients had problems. All this traditional rehabilitation programme was applied for 6 weeks, 5 days a week and 45 minutes a day.

The Lokomat® (Volketswil,Switzerland) is a robotic gait orthosis designed for use in neurorehabilitation, with the aim of automating locomotor functions. Consisting of a system that supported the user's human body weight and combined with a treadmill. This setup mimics the biomechanics of lower limb movement during above-ground walking and can be complemented by an interactive reality system. Lokomat® could be categorised into an exoskeleton robot. In such robots, linear electric motors drive knee and hip movements, guiding an orthosis attached to the user's body. In addition, during the swing phase, a foot lift mechanism produces passive dorsiflexion of the ankle (15). Supports a bilaterally symmetrical walking pattern by encouraging each individual to actively propel each limb when stepping on the treadmill. Lokomat® uses a previously programmed walking pattern that mimics normal walking kinematics. These include synchronisation of the walking cycle, cooperation between extremities and joints, and proper distribution of the load on the limbs to facilitate effective rehabilitation (16). The participants in our study participated in training on different games, from simple to difficult levels, for 6 weeks, 3 days a week, 30 minutes a day, using the Lokomat® lower extremity robotic device. The aim of the games was to improve mobility, increase lower extremity functionality, and improve QoL and improve mobility and daily activities.

During the initial session, clinical assessments were conducted, which included gathering personal information such as gender, age, height, weight, educational background, and the level of injury through direct questioning. Various assessment tools were then used at both the beginning and end of the six-week robotic rehabilitation and traditional neurological rehabilitation treatment program. The Scale of Spinal Cord Independence (SCIM III) was used to assess the participants' performance in activities of daily living and mobility, World Health Organization Quality of Life Scale (WHOQOL-BREF) was used to measure the participants' quality of life, and the Modified Borg Scale (RPE) was used to

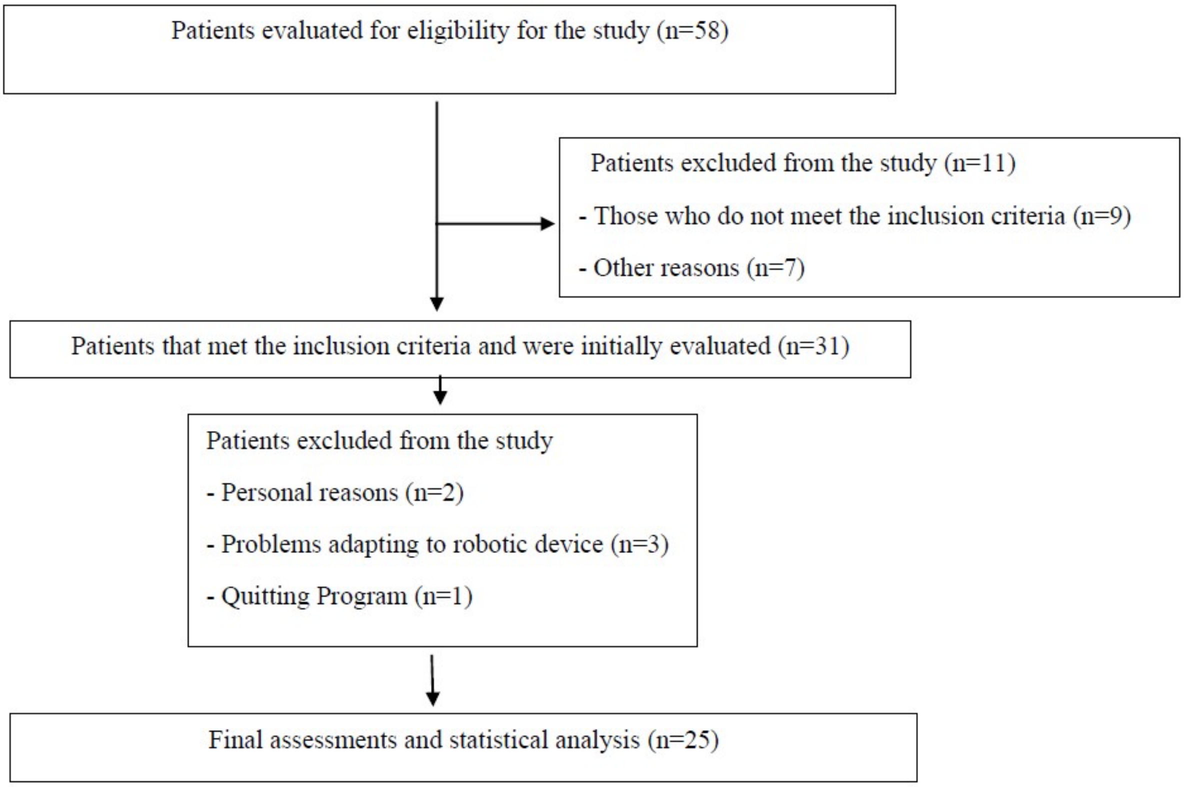

Figure 1. CONSORT diagram

measure the level of fatigue experienced during the rehabilitation process.

Spinal Cord Independence Measure (SCIM III)

The SCIM III was developed to address three specific areas of functioning in individuals with SCI. Evaluates the person's ability in self-care tasks like feeding, self-grooming, bathing and dressing, as well as control over breathing and sphincter management. Additionally, it evaluates a patient's mobility skills, both in terms of bed and transfers and indoor/outdoor movement. Furthermore, the SCIM III serves as a diagnostic tool for clinicians to identify aims and objectives of care for individuals with SCI. It's notable for its user-friendly nature, as the scoring system is self-explanatory and doesn't require a manual to guide clinicians through the scoring process. The SCIM III scores are quantified on a scale that spans from 0 to 100. While a score of zero means complete dependence, a score of one hundred means complete freedom. Each subscale score within the SCIM III evaluation corresponds to this 100-point scale. In particular, the sub-scale for self-care ranges from 0 to 20, the subscale for respiratory and sphincter administration ranges from 0 to 40, and the subscale for mobility ranges from 0 to 40. This allows for a detailed assessment of an individual's functional independence in various aspects of daily living and mobility (17). The Turkish validity and reliability of the scale was determined by Kesiktas et al (18)

World Health Organization Quality of Life Scale (WHOQOL-BREF)

WHOQOL-BREF is a condensed version of WHOQOL-100 and both were published in 1995, developed by WHO. This comprehensive questionnaire was created through a collaborative effort spanning several years and involving 15 centers worldwide. The questions in the WHOQOL-BREF reflect the perspectives of individuals with and without health problems and the views of health professionals, utilizing a variety of statements related quality of life, health and well-being. The WHOQOL-BREF is a self-administered survey that comprises 26 questions. Investigates individuals' perceptions of themselves regarding their health and well-being during the previous fortnight. The answers to these questions are evaluated according to a 1-5 Likert scale, with a score of 1 meaning "disagree" or "strongly disagree" and a score of 5 meaning

Table 2. Comparison of baseline and post-treatment parameters

	Baseline	Post-treatment	P	Cohens-d
	Mean±SD	Mean±SD		
SCIM III self-care (0-25)	10.16±3.13	12.32±2.06	0.006*	0.815
SCIM III breathing and sphincter control (0-35)	24.04±6.51	24.36±3.87	0.406	0.060
SCIM III mobility (0-40)	9.76±4.72	8.32±3.88	0.004*	0.333
SCIM III total (0-100)	43.52±12.97	45.00±8.27	0.076	0.136
WHOQOL-BREF- General health condition (%)	48.31±11.72	57.31±7.83	<0.001*	0.903
WHOQOL-BREF- Physical health (%)	41.88±10.17	49.67±6.79	<0.001*	0.901
WHOQOL-BREF-Psychological (%)	38.57±9.55	45.85±6.26	<0.001*	0.902
WHOQOL-BREF- Social relations (%)	57.96±14.07	68.77±9.39	<0.001*	0.904
WHOQOL-BREF- Environment (%)	64.20±15.72	75.96±9.03	<0.001*	0.917
RPE (6-20)	15.68±2.98	8.92±2.77	<0.001*	2.350

SCIM: Spinal Cord Independence Measure, RPE: The Modified Borg Scale, WHOQOL-BREF: The World Health Organization Quality of Life Scale – Short Form, SD: Standard deviation, d: Cohen effect size *Shapiro-Wilk test; significance was accepted as p<0.05.

"strongly agree" or "strongly agree". WHOQOL-BREF assesses four different domains, each of which has specific aspects: Psychological well-being, Physical health, social relationships and Environment. In addition, there are two separate questions that directly question the person's general health perception and general QoL (19). The Turkish validity and reliability of the scale was determined by Eser et al (20).

The Modified Borg Scale (RPE).

The Modified Borg Scale, also known as the Rate of Perceived Exertion (RPE), is a method used to assess the intensity of physical activity based on personal sensations like increased heart rate, breathing rate, sweating, and muscle fatigue. It ranges from 6 to 20, with 6 indicating no exertion and 20 indicating maximal effort. Typically, an RPE of 12 to 14 is considered moderate intensity. Monitoring RPE helps adjust exercise intensity in real time to match fitness goals and comfort levels, making it a valuable tool for gauging and managing workout intensity (21).

Statistical Analysis

The sample size was calculated using the G-power program. The SCIM III score in the reference article was calculated with a 1% margin of error and a confidence interval of 0.99, and it was deemed sufficient to include 23 people in the study (22). Analyzing the data obtained in the study "SPSS (Statistical Package for Social Sciences) (SPSS 22.0, SPSS, Chicago, IL)" statistical programme was used, p<0.05 (two directional) values are statistically considered significant. Study data whether it shows normal distribution using the Shapiro-Wilk test evaluated. The study data were analyzed as normal distribution was found to be appropriate. The study in the statistical analysis, the evaluation variables taken are minimum, maximum, average (Mean), standard deviation (SD) and percentage (%) were defined with values. To compare the values of the patients before and after treatment, Paired Sample t-test was used. According to Cohen's d value, if the d value was less than 0.2, the effect size was considered weak, if the d value was 0.5, the effect size was considered moderate and if the d value was greater than 0.8, the effect size was considered strong (23).

Ethical Considerations

The study received ethical approval from the Bakirkoy Dr. Sadi Guest Training And Research Hospital Clinical Research Ethics Committee (Date: 19.06.2017, Decision No: 2017-06-24), and conducted in accordance with the principles set out in the Declaration of Helsinki.

RESULTS

The research involved a cohort of 25 individuals with SCI for various reasons. The majority of these people consist of male participants (%72). Detailed demographic information and the neurological levels of the participants can be found in Table 1. Among the SCI individuals included in the study, 12 were AIS A (48%), 6 were AIS B (24%), 4 were AIS C (16%) and 3 were AIS D (12%). Furthermore, the mean duration of injury of the participants was 2.60±1.66 years.

Statistical analysis revealed notable findings in this study. In particular, an improvement of 2.16 points in the self-care subscore (p= 0.006) of the SCIM III scale and a 1.44-point improvement in the mobility sub-score (p= 0.004) were achieved. It was observed that there was a significant difference compared to the pre-treatment values of these two sub parameters. However, significant difference was not observed in respiratory and sphincter control sub-parameters (p=0.406). Additionally, when the WHOQOL-BREF scale was examined, an improvement of 7.79 points in the physical health sub-score (p<0.001), 7.28 points in the psychological sub-score (p<0.001), 11.76 points in the environmental sub-score (p<0.001), 10.81 points in the social relations sub-score (p<0.001) and 9.00 points in the general health sub-score (p<0.001) was achieved. All sub-parameters showed statistical differences compared to pre-treatment values. This suggests changes in the participants' perceived QoL across these domains. Additionally, a significant decrease with a 6.76 point improvement in the RPE value, which is used to evaluate the level of fatigue during effort in robotic walking training, is a remarkable result (p<0.001). These findings are synthesized in Table 2, which provides a comparative analysis of pre- and post-treatment parameters. In our study, the SCIM III mobility parameter had a low effect size (<0.5) in the Cohen-d effect size values of the parameters that were significant when comparing the pre- and post-treatment values; Our other parameters were found to have a high effect size (>0.8) (see table 2).

DISCUSSION

This study includes an attempt to assess independence, quality of life, activity level and fatigue during activity in individuals with SCI using robotic-assisted physiotherapy in combination with conventional physiotherapy. In our study, specialised assessment tools were used to assess independence in daily living and disease-specific clinical status, which are specific to individuals with SCI. The potential of developments in the area of assistive technologies is both extensive and varied, as demonstrated by the many studies that have examining their effectiveness and clinical applications. We found a remarkable improvement in SCIM III self-care and mobility levels, similar to the results of robotic-assisted rehabilitation in the literature. While a positive increase was observed in other parameters (breathing and sphincter control and total score), this increase was not statistically significant. We think that robotic walking aids used in SCI rehabilitation increase the independence of the individual. These advancements hold great promise for various applications, including assisting individuals in tasks, aiding in rehabilitation, enhancing mobility, and improving brain connectivity.

Research in this area has illuminated the efficacy, uptake and value of using assistive technologies as therapeutic interventions and means of self-management among persons with SCI (10). Considering the literature, it is seen that assistive robotic devices are used in many areas and in many subjects. When we look at similar studies on this subject; the pilot study revealed that robotic-assisted ambulation positively affected individuals with SCI. They noted that participants showed improvements in walking, mobility, overall quality of life, increased self-confidence and decreased dependence on caregivers, and that exoskeleton technology has the potential to improve both the physical and psychological health of people with SCI (24). In the clinical trial, it was observed that robotic-assisted gait training can lead to significant improvements in motor function, particularly for individuals with incomplete SCI. It was stated that the participants in the group receiving robotic-assisted gait training showed significant improvements in motor recovery significantly improved gait in comparison to the control group (25). In another study found that robotic gait training had a positive impact on cardiovascular condition in individuals with SCI. Participants experienced improved cardiovascular fitness and circulation as a result of the training. The results indicated that this form of rehabilitation not only enhances mobility but also contributes to overall health. However, the study recognized the need for tailored approaches for varying degrees of SCI and emphasized the importance of long-term studies to fully understand the cardiovascular benefits (26). Conducted in another study explored the psychological impact of assistive technologies on the QoL for individuals with SCI. The results indicated that these technologies can have a positive effect on mental well-being by increasing independence and self-esteem. The study emphasized that assistive technologies could mitigate psychological challenges associated with SCI, same as depression and feelings of helplessness (27). Robotic-assisted gait training, specifically using the Lokomat system, has shown positive effects on motor impairments including walking speed, walking distance, effort, range of motion and locomotion in persons with SCI (28). It has been stated that improved functional independence, measured by SCIM III, is associated with sitting balance and wheelchair skills in full-time wheelchair users with SCI (29). Individuals with SCI, especially those with paraplegia, show good functional autonomy in self-care, respiration and incontinence management, but may experience limitations in mobility, particularly in tasks such as climbing stairs and transferring from the ground to a wheelchair (30). In two different robotic walking rehabilitation studies that evaluated using SCIM, both studies reported positive improvements in ADL independence, but no significant results were found (31, 32). As a result of the evaluation we made using SCIM in our study; While there was an improvement in breathing and sphincter control and total score at the end of the treatment, no significant results were observed. A statistically significant difference was found in the self-care and mobility sub-scores. Moreover, low effect size for SCIM III mobility and high effect size for SCIM III self-care were observed after the treatment. If we examine it from this dimension, we see that we obtain more positive and meaningful results as a result of not working. It can be thought that robotic walking training applied in addition to the traditional neurological rehabilitation program may have a positive and significant contribution to ADL activities, depending on physical characteristics.

The integration of robotic-assisted gait training alongside conventional rehabilitation has demonstrated favorable outcomes for individuals with subacute complete SCI (33). They stated that as a result of four studies examined on QoL in the review on robotic walking training, both standing upright and the use of robotic walking devices consistently improved health-related QoL measurements (34). In another more comprehensive review, 12 articles on QoL were examined and as a result, it was stated that robotic walking training had positive effects on QoL (2). A recent study similarly stated that lower extremity robotic walking training may have potential benefits in terms of QoL and daily living activities in SCI patients (35). This combined approach has been shown in the literature to have beneficial effects on the functional independence, mobility, and overall QoL of these individuals. Similarly, in our study, statistically significant differences were observed in all sub-parameters of the WHOQOL-BREF scale. Considering these significant differences, it can be concluded that assistive robotic devices have a positive impact on the QoL of individuals with SCI. Especially when we evaluated the size of the effect size after the comparison of the results, it was seen that we obtained a high effect size in all parameters. We think that this shows that the effectiveness of the treatment is high.

The perceived level of fatigue was another parameter evaluated in our study. In the preliminary study conducted by Sale et al. on Wearable Robot Technologies on individuals with SCI, they found the Borg scale values as 3 ± 3.464 and T1 1.667 ± 1.155. They stated that they recorded a 36% improvement in RPE values (36). Corbianco et al., in their study comparing lokomat and exoskeleton robotic rehabilitation applications, stated that they found the RPE value to be 4-5/10 and that there was no difference between the two different robotic rehabilitation applications (37). McIntosh et al.'s studies reported that perceived exertion was on average "moderate" (mean 3.1 and 3.0) at both the midpoint and end points of a robotic rehabilitation session (38). Escalona et al., in their study using robotic exoskeleton, found the median RPE value to be 3.2, similar to the literature (39). In our study, we recorded an average improvement of 6.76 points after the intervention compared to the pre-treatment RPE values. When we look at the effect size, we see that we obtained a high effect size result. With the training, we achieved a similar improvement in perceived exertion levels as in the literature. In the literature, it is seen that the number of studies evaluating RPE after robotic rehabilitation is limited and the sample size of these studies is low. One of the advantageous aspects of our study is that we have a larger sample size compared to the literature. It is predicted that fatigue levels in individuals with SCI will decrease as the level of exertion increases. Therefore, it can be concluded that the use of assistive robotic devices may contribute to the reduction of fatigue in this population.

Limitations

Studies in this area often face challenges in recruiting a sufficiently large and diverse sample of individuals with SCI. Restricted sample size may make generalising findings to a wider population difficult, while lack of variation may limit the applicability of findings to a diverse subsample of individuals with SCI. SCI can differ greatly in terms of severity and extent of injury and specific impairments. That heterogeneity may make it difficult to reach broad conclusions about the effects of assistive robotic technologies, because what works for one individual may not work for another.

To establish the true impact of assistive robotic technologies, it is crucial to conduct well-designed comparative studies with appropriate control groups. However, finding suitable control groups can be challenging.

The successful integration of assistive robotic technologies often depends on proper training and adaptation. Studies should consider the learning curve and adaptation period required for users to achieve optimal benefits.

CONCLUSION

Assisted robotic rehabilitation approaches increased individual independence, QoL and reduced fatigue during exertion in Individuals with SCI. We think that assisted robotic approaches applied in addition to traditional rehabilitation provide additional benefits in increasing the level of independence and QoL of individuals with SCI in daily life and reducing fatigue during exertion.

Main points: The use of assistive robotic technologies can help in regaining some level of independence and performing daily activities, which can positively affect psychological and emotional well-being.

Assistive robotic technologies such as exoskeletons, wheelchair-mounted robotic arms, or adaptive computer interfaces can assist with mobility, self-care, and communication with spinal cord injuries.

The use of assistive robotic technologies can help in regaining some level of independence and performing daily activities, which can positively affect psychological and emotional well-being.

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Conflict of interests: None.

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