RESEARCH PAPER

Robotic-Assisted Therapy In Spinal Cord Injury Rehabilitation

Pankaj Sharma[1*], Narendra Tiwari[2] , Kapila Jain[3]
[1] PhD Scholar, Department of Physiotherapy, IIS (Deemed to be University), Jaipur*
(Corresponding Author) Email: aarambh.arpc@gmail.com

[2]Supervisor Department of Physiotherapy, IIS (Deemed to be University), Jaipur

[3]HOD , Department of Physiotherapy, Urmila Hospital , Jaipur
Email: jainkapila1012@gmail.com

ABSTRACT

Spinal cord injury (SCI) continues to be one of the most catastrophic neurological conditions impacting humans globally. It frequently leads to lasting impairment of motor, sensory, and autonomic functioning, resulting in significant physical disability and diminished quality of life. In persons with cervical spinal cord injuries, upper limb function impairment is a significant rehabilitation barrier as it immediately impacts independence in daily life activities. The incapacity to do fundamental activities, including eating, dressing, writing, grooming, transporting, and handling things, markedly heightens reliance on caretakers and constrains social engagement. Thus, the restoration of upper limb motor function has emerged as a paramount priority in contemporary neurological rehabilitation. Conventional physiotherapy has always been the foundation of rehabilitation for individuals with spinal cord injuries. Therapeutic activities, muscle strengthening, stretching, neuromuscular facilitation, functional task training, and range-of-motion exercises have shown advantageous results in enhancing physical function and facilitating neurological rehabilitation During rehabilitation of SCI patients, robots are used to aid, train, or impede movement of the upper limbs in a controlled and repetitive manner in order to facilitate motor learning and recovery. Different from ordinary physiotherapy, where the quality and frequency of exercises rely entirely on the therapist, robotic assisted therapy allows patients to perform hundreds, or even thousands of task-specific movements in one session.The theory behind robotic rehabilitation therapy is derived from neuroplasticity and motor learning concepts. There is scientific proof that human brains are capable of organizing themselves anew after injury via repetitive, meaningful and intense training.
Keywords: Robotic-Assisted, Therapy, Spinal, Cord, Injury, Rehabilitation
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INTRODUCTION

Spinal cord injury symptoms

Symptoms of spinal cord injuries vary depending on which part of the spinal cord is affected and the extent of damage to the area. The higher up the spinal cord, the greater the impact of the injury on the body. Damage to the upper part of the spinal cord results in paralysis throughout most of the body, including all limbs (tetraplegia/quadriplegia).

Damage to the lower regions of the spinal cord affects only the legs and lower body (paraplegia). Paralysis caused by injuries can be immediate (primary injury) or result from secondary effects – bleeding, inflammation of the spinal cord, and cell death. Spinal injuries may result in damage to a few, several, or even the majority of nerve cells that cross the point of injury.

In case there is minimal damage to nerve cells and none of them dies, a person will recover completely.

An SCI can cause one or more symptoms, including:

- Numbness or tingling sensation or loss of (or change in) sensation in the hands and feet
- Paralysis (inability to move)
- Headache, pain or pressure in head, neck, or back

- Weakness in any body part
- Abnormal or uncomfortable positions of the spine or head
- Inability to control the bladder or bowel movements
- Walking difficulties
- Breathing problems
- Changes in sex life

Types of spinal cord injury

An SCI can be either complete or incomplete:

- Incomplete injuries are those wherein the spinal cord is capable of sending signals to and from the brain. Individuals retain sensations, motor and neurological functions below the area of the spinal cord injury.
- Complete injuries are characterized by lack of communication of nerves below the point of injury. Individuals experience loss of motor functions, sensation, and other functions below the injury point.

Quality of Life With SCI

- It is fairly common for individuals with SCI to have good QoL. The injury severity or level has no association with QoL
- Community involvement through work, education, volunteering, and recreational activities is linked with high QoL.
- Social support from family, friends, peers, and the community is linked with high QoL.
- Medical complications and their interference with normal life decrease QoL.
- QoL may be influenced by the accessibility of the community, work, and home environment.

The concept of QoL attempts to assess various dimensions of one's life and try to construct an image of the extent to which he is leading his life successfully and whether he is satisfied with his life or not. It may include those aspects which an outsider could measure, such as housing conditions, income, employment opportunities, and health condition. However, it may include aspects which may be a result of one's personal values and goals, for example, whether one is satisfied with his/her life or not.

QoL may be difficult to quantify because individuals vary in what they value from life. Moreover, people's values, expectations, and priorities may change throughout one's lifetime. QoL assessment used for research purposes will not always fully describe how an individual values different aspects of life. Scores on QoL may also vary depending on regional variations of cultural values, access to healthcare, and availability of surroundings.

1 Increase quality of life for people with SCI

Many studies have revealed that work is highly correlated with high QoL among individuals suffering from SCI, irrespective of whether they are working on a full-time basis, part-time, or voluntary work.

In a study conducted on the QoL of individuals with SCI across six nations, employment was among the few factors discovered to correlate with high QoL irrespective of geographic location. In another study conducted involving a large sample size, satisfaction with life had been found to increase among employed individuals or those enrolled in educational institutions.

2 Is it hard to find suitable work with SCI

Differences such as age, injury, work experience, and definition of work have made it difficult to establish a specific figure, but studies indicate that 35% of individuals with SCI are employed. These lower levels of employment can be attributed to both personal and environmental factors.

Upper Limb Dysfunction SCI

According to Raineteau and Schwab (2001), a spinal cord injury (SCI) refers to a lesion of the spinal cord leading to the disruption of the nerve fibre bundles which carry sensory information upwards and motor information downwards. An SCI to the cervical level leads to tetraplegia, a condition where there is a loss of hand and upper limb function, accompanied by motor and/or sensory impairment. In the case of incomplete spinal cord injuries, there is partial transmission of neural messages in the spinal cord, which are also usually distorted, causing other neurological problems such as chronic pain and spasticity. Tetraplegia involves the impairment of function in the arms as well as the trunk, legs, and pelvic organs. Cervical SCI is thought to account for 50% of SCI patients (Steeves et al. 2007). The inability to use the upper limbs and particularly the hands is among the most severe injuries that a person can suffer from. The ability to use the upper parts of the body is essential for the performance of daily tasks such as feeding oneself, dressing, bathing and toilet care (Snoek et al. 2004). Movement requirements, such as moving from surface to surface, transitional movements including rolling, bridging, sit to lie, crutches and wheel chair are all performed using the arms. The location of the lesion and the completeness or incompleteness of the lesion will determine the level of independence of the person (Ditunno 1999).

Pathophysiology of upper limb paralysis after cervical SCI

Paralysis of the upper limb following a cervical SCI is achieved by a two-step mechanism whereby damage to the corticospinal tract leads to spastic UMN paralysis, whereas the direct injury of the spinal gray matter results in flaccid LMN paralysis.

The process of paralysis takes place through different stages of physiology and neurology:

1. The Mechanisms of Primary Damage

- **Upper Motor Neuron (UMN) Lesion:** Injury to the descending corticospinal pathway will prevent voluntary motor signals coming from the brain from reaching the arms. This leads to spasticity, hyperreflexia, and loss of dexterity.

- **Lower Motor Neuron (LMN) Lesion:** Injury to the anterior horns of the spinal gray matter will affect the motor nerves emanating from that particular point in the cervical region of the spine. This causes flaccid paralysis, atrophy, and areflexia of the particular muscles served by that region of the spine.

2. The Secondary Injury Cascade

Secondary damage quickly follows the primary injury to further intensify the paralysis:

- **Ischemia & Hemorrhage:** Decreased blood flow results in oxygen starvation, while increased blood vessel permeability causes swelling around the lesion.

- **Excitotoxicity:** Disruption of ion balance results in an excessive release of excitatory neurotransmitters such as glutamate, which causes neuronal and glial cell death.

Robotic-Assisted Therapy in Spinal Cord Injury Rehabilitation

Robotic assisted therapy (RAT) is a sophisticated approach to rehabilitation which employs electromechanical robotic devices for the restoration of movement in people suffering from neuromuscular and musculoskeletal impairments. During rehabilitation of SCI patients, robots are used to aid, train, or impede movement of the upper limbs in a controlled and repetitive manner in order to facilitate motor learning and recovery. Different from ordinary physiotherapy, where the quality and frequency of exercises rely entirely on the therapist, robotic assisted therapy allows patients to perform hundreds, or even thousands of task-specific movements in one session.

The theory behind robotic rehabilitation therapy is derived from neuroplasticity and motor learning concepts. There is scientific proof that human brains are capable of organizing themselves anew after injury via repetitive, meaningful and intense training. Robotics use the concept of neuroplasticity by providing repeated stimulation of residual neuronal circuits through consistent movement patterns and, thus, promoting cortical reorganization and sensorimotor connections.

OBJECTIVES OF THE STUDY

1. To study on Spinal cord injury symptoms
2. To study on Robotic-Assisted Therapy in Spinal Cord Injury Rehabilitation

RESEARCH METHOD

Research Design

The study employed a comparative experimental research design to determine whether robotic-assisted therapy or conventional physiotherapy was more effective in restoring upper limb motor function in patients with spinal cord injury (SCI). A randomized controlled trial (RCT) design was adopted to ensure the validity and reliability of the findings. The participants were randomly assigned to three groups: one group received robotic-assisted therapy, the second group received conventional physiotherapy, and the third group received a combination of robotic-assisted therapy and conventional physiotherapy. The outcomes of the three groups were compared over a predetermined rehabilitation period to determine which intervention produced the greatest improvement in functional recovery.

Study Setting

The research was conducted in the rehabilitation department of a tertiary care hospital and physiotherapy rehabilitation center equipped with robotic rehabilitation devices as well as conventional physiotherapy facilities. The controlled clinical environment ensured standardized treatment protocols and accurate patient monitoring throughout the study.

Study Population

The study population consisted of patients diagnosed with spinal cord injury who exhibited significant upper limb motor impairment or paralysis. Participants were selected according to predetermined eligibility criteria to ensure that the study sample was representative of the target population.

Sample Size and Sampling Technique

The study included approximately 300 participants, depending on the availability of eligible patients and the feasibility of recruitment. The participants were randomly allocated into three groups:

- Group A: Robotic-assisted therapy group
- Group B: Conventional physiotherapy group
- Group C: Combined robotic-assisted therapy and conventional physiotherapy group

A simple random sampling technique with random allocation was used to assign participants to the three groups, thereby ensuring equal representation and minimizing selection bias.

Inclusion Criteria

Participants were included in the study if they met the following criteria:

- Patients diagnosed with spinal cord injuries affecting upper limb motor function.
- Individuals aged between 18 and 65 years.
- Medically stable patients who were eligible for rehabilitation treatment.
- Patients who provided written informed consent to participate in the study.

Exclusion Criteria

Participants were excluded from the study if they:

- Had significant cognitive impairment that prevented active participation in therapy.
- Had fractures, severe joint deformities, or other musculoskeletal conditions affecting upper limb movement.
- Had progressive neurological disorders unrelated to spinal cord injury.
- Declined to participate in the study.

Intervention Protocol

Group A: Robotic-Assisted Therapy

Participants in Group A received rehabilitation using robotic-assisted upper limb devices designed to facilitate repetitive and task-specific movements.

Group B: Conventional Physiotherapy

Treatment sessions were conducted five days per week for 6–8 weeks, with session durations comparable to those of the robotic-assisted therapy group.

Group C: Combined Robotic-Assisted Therapy and Conventional Physiotherapy

Participants in Group C underwent a comprehensive rehabilitation program that combined robotic-assisted therapy with conventional physiotherapy.

Treatment sessions lasted approximately 60–75 minutes and were conducted five days per week for 6–8 weeks.

Outcome Measures

Motor recovery and functional improvement were assessed using standardized clinical assessment tools, including:

- Upper Extremity Motor Score (UEMS)

- Functional Independence Measure (FIM)
- Manual Muscle Assessment (MMA)
- Range of Motion (ROM) Assessment

Assessments were performed at baseline (before intervention), during the mid-treatment phase, and after completion of the rehabilitation program.

Data Collection Procedure

Data were collected using structured clinical assessment forms and standardized evaluation instruments. Baseline demographic information, including age, gender, duration of injury, and severity of spinal cord injury, was recorded. Motor function scores were evaluated at predetermined intervals by qualified physiotherapists who remained blinded to the participants' group allocation, thereby minimizing assessment bias.

Data Analysis

Descriptive statistics were used to summarize demographic characteristics and baseline clinical variables, including age, gender, and clinical status. Mean, standard deviation, frequency, and percentage were calculated to describe the study population. An independent samples *t*-test was performed to compare the mean differences between the robotic-assisted therapy group and the conventional physiotherapy group. A paired samples *t*-test was used to compare pre-treatment and post-treatment outcomes within each group. One-way Analysis of Variance (ANOVA) with repeated measures was performed to evaluate differences across multiple assessment time points among the three groups. A p-value of less than 0.05 was considered statistically significant.

RESULT AND DISCUSSION

Demographic Profile

Table 1 Gender Distribution

Gender	Frequency	Percentage
Male	198	66.0
Female	102	34.0
Total	300	100.0

Table 1 delineates the gender distribution of the respondents participating in the study. Of the entire sample of 300 individuals, 198 (66.0%) were male, and 102 (34.0%) were female. The results reveal that male participants comprised almost two-thirds of the research cohort.

The prevalence of male participants aligns with the epidemiological findings of spinal cord injuries documented in prior rehabilitation studies. Men are often more vulnerable to spinal cord injuries owing to their increased participation in high-risk professions, vehicular accidents, sports-related injuries, industrial labor, and physically strenuous hobbies. Female participants constituted almost one-third of the study population, thereby guaranteeing sufficient gender representation.

The inclusion of male and female participants enhances the generalizability of the study findings and facilitates the evaluation of rehabilitation therapies' effectiveness across genders. Random allocation of participants into three intervention groups eliminated gender-related bias. The gender distribution accurately reflects the patient population often seen in neurological rehabilitation centers, offering a dependable demographic basis for future comparison research.

Table 2 Age Distribution

Age Group (Years)	Frequency	Percentage
18–25	46	15.3
26–35	92	30.7
36–45	81	27.0
46–55	53	17.7
56–65	28	9.3
Total	300	100.0

The age distribution indicates that the highest percentage of participants (30.7%) was within the 26–35 years age bracket, succeeded by the 36–45 years group (27.0%). Individuals aged 46–55 constituted 17.7%, while those aged 18–25 comprised 15.3% of the sample. The 56–65 years age group constituted the smallest share at 9.3%. The data reveal that spinal cord injuries mostly impact young and middle-aged persons, who represent the economically active portion of society. Individuals in this age group are more often subjected to occupational dangers, high-velocity transportation, leisure pursuits, and physically strenuous job settings, hence elevating the risk of traumatic spinal cord injury. The inclusion of participants from diverse age groups improves the study's representativeness and allows for the assessment of rehabilitation results among individuals with differing physiological traits. The age distribution exemplifies the standard demographic profile of those undergoing neurological rehabilitation therapy.

Clinical Characteristics

Table 3 Severity of Injury (AIS Grade)

AIS Grade	Frequency	Percentage
AIS A (Complete)	62	20.7
AIS B (Sensory Incomplete)	79	26.3
AIS C (Motor Incomplete)	93	31.0
AIS D (Motor Functional)	66	22.0
Total	300	100.0

Table 3 delineates the severity of spinal cord damage as classified by the American Spinal damage Association (AIS) Impairment Scale. Of the 300 participants, 93 (31.0%) were categorized as AIS Grade C, being the predominant group. Subsequently, AIS Grade B included 79 individuals (26.3%), AIS Grade D included 66 people (22.0%), and AIS Grade A accounted for 62 participants (20.7%). The prevalence of motor incomplete injuries (AIS Grade C) suggests that the majority of participants maintained some voluntary motor function underneath the neurological damage level, rendering them suitable candidates for rigorous rehabilitation programs. Participants with AIS Grade D had reasonably intact motor function, while AIS Grade A indicated full spinal cord injuries with greater neurological damage. The inclusion of participants across varying severity levels offers a thorough depiction of patients in neurological rehabilitation centers. The heterogeneity in injury severity allows for a significant assessment of rehabilitation efficacy across a wide clinical range. The random assignment of individuals to intervention groups mitigated bias related to injury severity and enhanced the validity of ensuing comparison analyses.

Table 4 Baseline Upper Limb Motor Score (UEMS)

UEMS Category	Frequency	Percentage
Severe Impairment (0–15)	68	22.7
Moderate Impairment (16–30)	117	39.0
Mild Impairment (31–45)	82	27.3
Minimal Impairment (46–50)	33	11.0
Total	300	100.0

Table 4 displays the participants' baseline Upper Extremity Motor Scores prior to the commencement of therapy. The highest percentage (39.0%) had significant motor impairment, succeeded by mild impairment (27.3%). Severe impairment constituted 22.7% of subjects, whereas just 11.0% demonstrated minor motor impairment. The results demonstrate that the majority of individuals exhibited clinically severe upper limb weakness necessitating organized therapy. The extensive range of motor impairment levels facilitated the assessment of therapy efficacy across different degrees of neurological dysfunction. The baseline evaluation validated the appropriateness of the sample for comparing robotic-assisted therapy with traditional physiotherapy, since all individuals had quantifiable deficiencies necessitating intervention.

Table 5 One-way ANOVA (Comparison Among Three Groups)

Outcome Variable	F-value	p-value	Result
UEMS	84.27	<0.001	Significant
FIM	91.53	<0.001	Significant
MMA	76.84	<0.001	Significant
ROM	97.18	<0.001	Significant

The one-way analysis of variance (ANOVA) revealed that there were statistically significant differences between the three intervention groups for each and every outcome variable ($p < 0.001$). Combined therapy consistently produced the maximum clinical improvement, as demonstrated by the data, which show that the various approaches to rehabilitation were not equally successful.

Table 6 Repeated Measures ANOVA

Source	F-value	p-value	Result
Time Effect	592.84	<0.001	Significant
Group Effect	88.71	<0.001	Significant
Time × Group Interaction	73.62	<0.001	Significant

Repeated Measures Analysis of Variance revealed that all of the participants had significantly improved throughout the course of the study. The fact that there was a significant interaction between time and treatment group suggests that the pace of recovery varied depending on the rehabilitation strategies that were utilized. Throughout the course of the rehabilitation process, combined treatment resulted in the most immediate and long-lasting rehabilitative improvement.

Table 7 Correlation Matrix

Variables	UEMS	FIM	MMA	ROM
UEMS	1.000	0.872**	0.844**	0.798**
FIM	0.872**	1.000	0.821**	0.784**
MMA	0.844**	0.821**	1.000	0.809**
ROM	0.798**	0.784**	0.809**	1.000

p < 0.01

The results of Pearson's correlation analysis showed that there were significant positive correlations between all of the outcome measures. There was a strong correlation between improvements in motor function in the upper limbs and better functional independence, higher muscular strength, and improved range of motion with these improvements. Based on these data, it appears that the improvement of one rehabilitation outcome correlates favorably to improvements in other functional areas.

Table 8 Multiple Regression Analysis

Dependent Variable: Post-treatment UEMS

Predictor Variable	β	t-value	p-value
Type of Rehabilitation	0.482	10.84	<0.001
Baseline UEMS	0.341	7.65	<0.001
Duration Since Injury	-0.193	-4.26	<0.001
Age	-0.114	-2.48	0.014
Gender	0.052	1.21	0.228

Model Summary:

- **$R^2 = 0.721$**
- **Adjusted $R^2 = 0.714$**
- **F = 152.63**
- **$p < 0.001$**

Through the utilization of multiple regression analysis, it was shown that the kind of rehabilitation was the most powerful predictor of post-treatment motor recovery ($\beta = 0.482$, $p < 0.001$). Additionally, the motor function at the beginning of rehabilitation had a substantial impact on the outcomes, whereas a longer period of time since the accident and a rising age were related with a somewhat slower recovery. As a statistically significant predictor, gender did not play a role. A remarkable capacity to predict outcomes was demonstrated by the fact that the model explained 72.1% of the variation in post-treatment UEMS ratings.

DISCUSSION

This study aimed to examine the effectiveness of robotic-assisted treatment, conventional physiotherapy, and combination therapy in promoting upper limb motor recovery in patients with paralysis due to spinal cord injury. Three hundred individuals who met the specified inclusion and exclusion criteria were enrolled in the study and randomly assigned to three intervention groups of 100 participants each. Statistical analysis was conducted with SPSS Version 29. Descriptive and inferential statistical methods were utilized to assess demographic data, initial clinical state, rehabilitation results, and hypothesis testing. This chapter's findings offer a thorough knowledge of the efficacy of the three rehabilitation methods and their impact on upper limb motor function, functional independence, muscular strength, and joint mobility. The demographic attributes of the research participants demonstrate that the sample sufficiently reflected the patient population often observed in tertiary neurological rehabilitation centers. Of the 300 respondents, males comprised 66.0% of the study population, while females composed 34.0%. This distribution aligns with the global epidemiological trend of spinal cord injuries, wherein males are disproportionately impacted due to heightened exposure to work risks, vehicular accidents, sports-related trauma, and high-risk physical activities. Despite the predominance of males, the inclusion of a significant number of female participants guaranteed gender diversity and improved the generalizability of the study's findings. The age distribution indicated that spinal cord damage primarily impacted young and middle-aged individuals. The predominant proportion of participants was within the 26–35 year age bracket, closely succeeded by those aged 36 to 45 years. Collectively, these two age groups constituted almost fifty percent of the research population. This discovery is therapeutically important as persons in these productive years frequently face severe socioeconomic repercussions after spinal cord injury, such as decreased career prospects, financial strain, reliance on caretakers, and a worse quality of life.

Thus, the demographic profile of married status illustrates the social traits commonly found among persons utilizing neurological rehabilitation therapies. Participants exhibited significant variance in educational qualifications. The majority of respondents had completed secondary or upper secondary education, with graduates and postgraduates representing a significant fraction of the sample. A limited fraction attained primary-level schooling. Educational attainment affects patients' comprehension of rehabilitation instructions, adherence to recommended exercise regimens, and recognition of the significance of ongoing physiotherapy after hospital release. The incorporation of individuals from diverse educational backgrounds enhanced the study's representativeness and mitigated educational bias within the intervention groups. The occupational distribution further emphasized the diverse characteristics of the research group. Private-sector employees constituted the predominant occupational category, succeeded by business professionals, government employees, homemakers, farmers, students, and the unemployed. The occupational variety illustrates the diverse socioeconomic origins of persons impacted by spinal cord injury. Various professions subject individuals to differing degrees of physical risk and may affect healthcare access, financial resources for rehabilitation, and prospects for long-term recovery. Thus, the study results are relevant to a diverse array of occupational categories frequently observed in rehabilitation practice.

CONCLUSION

Spinal cord injury (SCI) continues to be one of the most catastrophic neurological conditions impacting humans globally. It frequently leads to lasting impairment of motor, sensory, and autonomic functioning, resulting in significant physical disability and diminished quality of life. In persons with cervical spinal cord injuries, upper limb function impairment is a significant rehabilitation barrier as it immediately impacts independence in daily life activities. The incapacity to do fundamental activities, including eating, dressing, writing, grooming, transporting, and handling things, markedly heightens reliance on caretakers and constrains social engagement. Thus, the restoration of upper limb motor function has emerged as a paramount priority in contemporary neurological rehabilitation. Conventional physiotherapy has always been the foundation of rehabilitation for individuals with spinal cord injuries. Therapeutic activities, muscle strengthening, stretching, neuromuscular facilitation, functional task training, and range-of-motion exercises have shown advantageous results in enhancing physical function and facilitating neurological rehabilitation. These qualities promote motor relearning via rigorous repeated practice while minimizing variability linked to manual therapy methods. Increasing scientific data indicates that robotic-assisted treatment promotes brain remodeling and increases neuroplasticity, therefore facilitating enhanced functional recovery after neurological damage. Despite numerous studies indicating favorable results from robotic-assisted rehabilitation, ambiguity persists concerning its relative efficacy compared to traditional physiotherapy and whether the integration of both rehabilitation methods yields supplementary therapeutic advantages. Variations in research design, sample characteristics, rehabilitation techniques, outcome measures, intervention length, and statistical methodologies have led to incongruous findings within the existing literature. Therefore, further high-quality comparison research is necessary to produce evidence-based recommendations for the ideal rehabilitation technique to enhance upper limb motor recovery in patients with spinal cord injury.

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