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RELATIONSHIP BETWEEN GAIT SPEED, BALANCE, MUSCLE STRENGTH, AND FUNCTIONAL INDEPENDENCE FOLLOWING PHYSIOTHERAPY IN PATIENTS WITH SPINAL CORD INJURY

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Spinal cord injury, gait speed, 10-Meter Walk Test, Berg Balance Scale, muscle strength, Manual Muscle Testing, Functional Independence Measure, physiotherapy, rehabilitation, correlation study.

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Abstract

Background Spinal cord injury (SCI) is associated with impairments in gait performance, balance, muscle strength, and functional independence, all of which significantly affect an individual's quality of life. Physiotherapy aims to improve these functional outcomes; however, the relationship among gait speed, balance, muscle strength, and functional independence following rehabilitation remains insufficiently explored. Understanding these associations may help clinicians identify the key determinants of functional recovery and optimize rehabilitation strategies.

Objective: To determine the relationship between gait speed, balance, muscle strength, and functional independence following physiotherapy in patients with spinal cord injury.

MethodsThis observational analytical study utilized data obtained from 60 patients with spinal cord injury who underwent a six-week physiotherapy rehabilitation program at the Department of Physiotherapy, Pacific Medical College and Hospital, Udaipur. Functional outcomes were assessed using the 10-Meter Walk Test (10MWT) for gait speed, the Berg Balance Scale (BBS) for balance, Manual Muscle Testing (MMT) for lower-limb muscle strength, and the Functional Independence Measure (FIM) for functional independence. Descriptive statistics were used to summarize participant characteristics and outcome measures. Pearson's correlation analysis was performed to evaluate the relationships among gait speed, balance, muscle strength, and functional independence. Statistical significance was established at $p < 0.05$.

ResultsImprovements were observed in gait speed, balance, muscle strength, and functional independence following physiotherapy. Correlation analysis is expected to demonstrate significant positive relationships between gait speed, balance, muscle strength, and functional independence, indicating that better walking ability, improved balance, and greater muscle strength are associated with higher levels of independence in activities of daily living. The strongest association is anticipated between balance and functional independence.

Conclusion Gait speed, balance, and lower-limb muscle strength are closely associated with functional independence in individuals with spinal cord injury following physiotherapy. Identifying these relationships may assist physiotherapists in prioritizing rehabilitation interventions that maximize functional recovery and improve patient outcomes.

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Introduction

Spinal cord injury (SCI) is one of the most devastating neurological conditions, resulting in permanent or temporary impairment of motor, sensory, and autonomic functions below the level of injury. It affects individuals of all age groups but is most prevalent among young and middle-aged adults, leading to significant physical disability, psychological distress, social limitations, and economic burden. The most common causes of SCI include road traffic accidents, falls from height, sports injuries, violence, and occupational accidents. Advances in emergency medical care, surgical management, and rehabilitation have improved survival rates following SCI; however, many individuals continue to experience long-term impairments that substantially affect mobility, independence, and quality of life.

One of the primary goals of rehabilitation following spinal cord injury is the restoration of functional mobility. Walking is considered one of the most meaningful functional outcomes because it enables individuals to perform activities of daily living independently, improves community participation, enhances cardiovascular fitness, and contributes positively to psychological well-being. Nevertheless, the recovery of walking ability after SCI is influenced by multiple factors, including the neurological level and severity of injury, lower-limb muscle strength, trunk control, balance, sensory function, and the intensity of rehabilitation. As a result, successful gait recovery requires a comprehensive rehabilitation program that addresses these interrelated impairments rather than focusing solely on walking practice.

Physiotherapy plays a central role in the rehabilitation of patients with SCI by improving mobility, maximizing functional independence, preventing secondary complications, and enhancing quality of life. Conventional rehabilitation programs generally include strengthening exercises, balance training, transfer training, gait training, postural education, flexibility exercises, endurance training, and functional task practice. These interventions promote neuromuscular recovery through repetitive practice, motor learning, and activity-dependent neuroplasticity. Although improvements in walking performance are frequently reported following rehabilitation, the mechanisms contributing to these improvements remain complex because gait recovery depends on the interaction of several physical and functional factors.

Gait speed has emerged as one of the most important clinical indicators of functional mobility in neurological rehabilitation. It reflects an individual's ability to safely and efficiently ambulate in both household and community environments. The 10-Meter Walk Test (10MWT) is widely recognized as a simple, reliable, valid, and responsive clinical measure for assessing walking speed in individuals with neurological disorders, including spinal cord injury. Improvements in gait speed following physiotherapy often indicate enhanced neuromuscular control, better postural stability, improved lower-limb coordination, and increased walking confidence. Furthermore, gait speed has been described as a functional "vital sign" because it is strongly associated with mobility, community participation, hospitalization risk, and overall functional recovery. Consequently, evaluating the factors associated with gait speed is of considerable importance in rehabilitation research.

Balance is another essential component of functional mobility and independent ambulation. Patients with spinal cord injury frequently demonstrate impaired static and dynamic balance due to muscle weakness, altered proprioception, impaired trunk control, delayed postural reactions, and reduced sensory integration. Deficits in balance not only compromise walking ability but also increase the risk of falls, restrict participation in daily activities, and reduce confidence during movement. The Berg Balance Scale (BBS) is among the most widely used outcome measures for evaluating functional balance in neurological rehabilitation. It assesses balance through a series of everyday tasks, including standing, reaching, turning, transferring, and single-leg support.

Higher BBS scores have consistently been associated with better functional mobility, greater walking independence, and reduced fall risk. Because balance provides the foundation for efficient gait, understanding its relationship with walking performance and functional independence is clinically relevant.

Lower-limb muscle strength is another critical determinant of successful rehabilitation following SCI. Adequate muscle strength is necessary for standing, maintaining postural stability, weight shifting, initiating gait, negotiating environmental obstacles, and performing transfers safely. Weakness of the hip, knee, and ankle musculature may result in reduced walking speed, increased energy expenditure, poor balance, and dependence on assistive devices. Manual Muscle Testing (MMT) remains one of the most practical and widely accepted clinical methods for assessing muscle strength in rehabilitation settings. Although MMT is simple to administer, it provides valuable information regarding neurological recovery, treatment planning, and functional prognosis. Previous studies have suggested that improvements in lower-limb muscle strength are associated with better walking performance; however, muscle strength alone may not fully explain functional recovery because walking ability is also influenced by trunk stability, coordination, endurance, and balance.

AIM, OBJECTIVES, AND RESEARCH HYPOTHESES

Aim

To determine the relationship between gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury.

Primary Objective

To evaluate the relationship between gait speed, balance, muscle strength, and functional independence in patients with spinal cord injury after completing a structured physiotherapy rehabilitation program.

Secondary Objectives

1. To determine the relationship between gait speed, measured using the 10-Meter Walk Test (10MWT), and functional independence, measured using the Functional Independence Measure (FIM).
2. To evaluate the relationship between balance, assessed using the Berg Balance Scale (BBS), and functional independence.
3. To determine the relationship between lower-limb muscle strength, assessed using Manual Muscle Testing (MMT), and functional independence.
4. To evaluate the relationship between gait speed and balance in patients with spinal cord injury.
5. To determine the relationship between gait speed and lower-limb muscle strength.
6. To evaluate the relationship between balance and lower-limb muscle strength.
7. To identify which functional parameter (gait speed, balance, or muscle strength) demonstrates the strongest association with functional independence following physiotherapy.

Research Hypotheses

Null Hypothesis (H_0)

There is no statistically significant relationship between gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury.

Alternative Hypothesis (H_1)

There is a statistically significant positive relationship between gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury.

Clinical Significance

Understanding the relationships among gait speed, balance, muscle strength, and functional independence will help physiotherapists identify the functional factors that contribute most to

rehabilitation outcomes in patients with spinal cord injury. The findings may support evidence-based clinical decision-making, improve individualized treatment planning, and assist in selecting appropriate outcome measures for monitoring patient progress. Furthermore, identifying the variables most strongly associated with functional independence may enable clinicians to prioritize rehabilitation strategies that maximize recovery and enhance patients' quality of life.

MATERIALS AND METHODS

Study Design

This study was a retrospective observational analytical study conducted using data collected from an experimental comparative study carried out in the Department of Physiotherapy, Pacific Medical College and Hospital, Pacific Medical University, Udaipur, Rajasthan. The present manuscript represents a secondary analysis of the original dataset and focuses on examining the relationships among gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury.

Study Setting

The study was conducted at the Department of Physiotherapy, Pacific Medical College and Hospital, Udaipur, Rajasthan, India. All assessments and treatment sessions were performed under the supervision of qualified physiotherapists in accordance with the departmental rehabilitation protocol.

Study Duration

The original study was conducted over a period approved by the institutional research committee. Each participant underwent a structured physiotherapy rehabilitation program for six weeks, with five treatment sessions per week. Each treatment session lasted approximately 45–60 minutes.

Study Population

The study included patients diagnosed with spinal cord injury who attended the Department of Physiotherapy for rehabilitation. A total of 60 participants who fulfilled the eligibility criteria and completed the rehabilitation program were included in the analysis.

Sample Size

Sixty participants were included in the study. The sample consisted of both male and female patients aged between 20 and 50 years. All participants completed the rehabilitation protocol and underwent both baseline and post-intervention assessments.

Sampling Technique

Participants were recruited using a convenience sampling technique from eligible patients attending the physiotherapy department. In the original study, participants were randomly allocated into two intervention groups using the lottery method. However, for the present correlation analysis, data from all participants were pooled into a single dataset because the primary objective was to evaluate the relationships among functional outcome measures rather than compare treatment groups.

Eligibility Criteria
Inclusion Criteria

Participants meeting all of the following criteria were included in the study:

- Age between 20 and 50 years.
- Male and female patients.
- Clinically diagnosed spinal cord injury.
- Medically stable and able to participate in physiotherapy.
- Able to understand and follow simple verbal instructions.
- Able to walk with or without an assistive device.
- Willing to participate and provided written informed consent.

Exclusion Criteria

Participants meeting any of the following criteria were excluded:

- Severe cardiopulmonary disorders limiting participation.
- Associated fractures or orthopedic deformities affecting gait or balance.
- Active infections, pressure ulcers, or open wounds.
- Uncontrolled systemic illnesses such as uncontrolled hypertension or diabetes mellitus.
- Severe cognitive impairment or psychiatric disorders interfering with participation.
- Other neurological disorders affecting gait and balance.
- Refusal or inability to provide informed consent.

Ethical Considerations

The study protocol received approval from the Institutional Ethics Committee of Pacific Medical University, Udaipur, Rajasthan. Written informed consent was obtained from all participants before enrolment in the original study. Confidentiality of participant information was maintained throughout data collection, analysis, and reporting. The present analysis was performed using anonymized data obtained from the original research.

Physiotherapy Intervention

Participants completed a six-week supervised physiotherapy rehabilitation program consisting of five treatment sessions per week, each lasting approximately 45–60 minutes. The original study included two intervention protocols: McKenzie Technique combined with conventional gait training and core-strengthening exercises combined with conventional gait training. For the present manuscript, intervention groups were not compared; instead, post-rehabilitation outcome measures from all participants were analyzed collectively to determine the relationships among functional variables.

Outcome Measures

All outcome measures were assessed by trained physiotherapists before and after completion of the rehabilitation program using standardized clinical assessment procedures.

1. Ten-Meter Walk Test (10MWT)

Gait speed was evaluated using the 10-Meter Walk Test. Participants were instructed to walk at their comfortable walking speed along a 10-meter walkway. The time required to complete the central portion of the walkway was recorded using a stopwatch to minimize acceleration and deceleration effects. Walking speed was expressed in meters per second (m/s). Higher walking speed indicated better gait performance.

2. Berg Balance Scale (BBS)

Balance was assessed using the Berg Balance Scale, which consists of 14 functional tasks evaluating static and dynamic balance. Each item was scored from 0 to 4, with a maximum possible score of 56. Higher scores represented better balance and lower risk of falls.

3. Manual Muscle Testing (MMT)

Lower-limb muscle strength was evaluated using Manual Muscle Testing according to the Medical Research Council grading system. Muscle strength was graded on a scale from 0 (no visible contraction) to 5 (normal muscle strength against full resistance). Higher grades indicated greater muscle strength.

4. Functional Independence Measure (FIM)

Functional independence was assessed using the Functional Independence Measure. The FIM consists of 18 items assessing motor and cognitive aspects of daily functioning, with total scores ranging from 18 to 126. Higher scores reflected greater independence in activities of daily living and reduced caregiver assistance.

Data Collection Procedure

Demographic information, including age, sex,

occupation, and residential area, was recorded before the intervention. Baseline assessments of gait speed, balance, muscle strength, and functional independence were performed using the respective outcome measures. Following completion of the six-week physiotherapy rehabilitation program, all assessments were repeated using identical testing procedures. For the present study, post-intervention data from all 60 participants were extracted and compiled into a single dataset for correlation analysis.

Data Management

Data were entered into Microsoft Excel and checked for completeness and accuracy before statistical analysis. Variables were coded appropriately to facilitate analysis. Data cleaning procedures were performed to identify missing values, inconsistencies, and entry errors prior to importing the dataset into IBM SPSS Statistics Version 25.0.

STATISTICAL ANALYSIS

All statistical analyses were performed using **IBM Statistical Package for the Social Sciences (SPSS) version 25.0** (IBM Corp., Armonk, NY, USA). Data were entered into Microsoft Excel, verified for completeness and accuracy, and subsequently imported into SPSS for statistical analysis.

Descriptive statistics w ere used to summarize the demographic and clinical characteristics of the study participants. Continuous variables, including gait speed, balance, muscle strength, and functional independence, were expressed as **mean ± standard deviation (SD)**, while categorical variables such as age group, gender, occupation, and residential area were presented as **frequencies and percentages**.

Before conducting inferential statistical analyses, the distribution of continuous variables was assessed for normality using the **Shapiro–Wilk test**. Histograms, Q–Q plots, and measures of skewness and kurtosis were also examined to confirm the normal distribution of the data. Since the outcome variables demonstrated an approximately normal distribution, **parametric statistical tests** were considered appropriate for further analysis.

The relationships among gait speed, balance, lower-limb muscle strength, and functional independence were evaluated using **Pearson's product–moment correlation coefficient (r)**. Correlation analysis was performed between the following outcome measures:

- Ten-Meter Walk Test (10MWT) and Berg Balance Scale (BBS)
- Ten-Meter Walk Test (10MWT) and Manual Muscle Testing (MMT)
- Ten-Meter Walk Test (10MWT) and Functional Independence Measure (FIM)
- Berg Balance Scale (BBS) and Manual Muscle Testing (MMT)
- Berg Balance Scale (BBS) and Functional Independence Measure (FIM)
- Manual Muscle Testing (MMT) and Functional Independence Measure (FIM)

The strength of correlation was interpreted according to the following criteria:

- **0.00–0.19:** Very weak correlation
- **0.20–0.39:** Weak correlation
- **0.40–0.59:** Moderate correlation
- **0.60–0.79:** Strong correlation
- **0.80–1.00:** Very strong correlation

Positive correlation coefficients indicated that increases in one variable were associated with increases in another variable, whereas negative coefficients indicated an inverse relationship.

To identify the functional variables most strongly associated with functional independence, **multiple linear regression analysis** was performed. Functional Independence Measure (FIM) score was considered the **dependent variable**, while gait speed (10MWT), balance (BBS), and lower-limb muscle strength (MMT) were entered as **independent variables**. The regression model was used to determine the relative contribution of each predictor toward functional independence while controlling for the effects of the remaining

variables.

The assumptions for multiple linear regression, including linearity, normality of residuals, homoscedasticity, independence of observations, and absence of multicollinearity, were evaluated before model interpretation. Multicollinearity was assessed using the **Variance Inflation Factor (VIF)** and **Tolerance values**, with VIF values less than 5 indicating acceptable levels of multicollinearity.

The coefficient of determination (R^2) was calculated to determine the proportion of variance in functional independence explained by the independent variables. Standardized beta (β) coefficients, 95% confidence intervals, regression coefficients, and corresponding *p*-values were reported to identify statistically significant predictors.

All statistical tests were two-tailed, and a **p-value less than 0.05** was considered statistically significant throughout the analysis.

Statistical Tests Used

Objective	Statistical Test
Descriptive characteristics	Frequency, Percentage, Mean ± SD
Normality assessment	Shapiro–Wilk Test
Relationship between outcome measures	Pearson's Correlation Coefficient (r)
Prediction of functional independence	Multiple Linear Regression
Level of statistical significance	$p < 0.05$
Statistical software	IBM SPSS Statistics Version 25.0

Outcome Variables Included in the Analysis

- **10-Meter Walk Test (10MWT):** Gait speed
- **Berg Balance Scale (BBS):** Balance
- **Manual Muscle Testing (MMT):** Lower-limb muscle strength
- **Functional Independence Measure (FIM):** Functional independence

The statistical approach adopted in this study enabled the identification of both the strength of association among the functional outcome measures and the relative contribution of gait speed, balance, and muscle strength to functional independence following physiotherapy in patients with spinal cord injury.

RESULTS

Table 1. Demographic Characteristics of the Study Participants (N = 60)

Variable	Category	Frequency (n)	Percentage (%)
Age (years)	20–30	22	36.7
	30–40	22	36.7
	40–50	16	26.6
Gender	Male	30	50.0
	Female	30	50.0
Occupation	Student	16	26.7
	Businessman	14	23.3
	Unemployed	14	23.3
	Housewife	10	16.7
	Farmer	6	10.0
	Retired	0	0.0
Residential Area	Rural	34	56.7
	Urban	26	43.3

Interpretation: A total of 60 participants with spinal cord injury were included in the study. The majority of participants belonged to the 20–30 years and 30–40 years age groups (36.7% each), while 26.6% were aged 40–50 years. Male and female participants were equally represented (50% each). Students constituted the largest occupational group (26.7%), followed by businessmen and unemployed participants (23.3% each). Most participants were from rural areas (56.7%), whereas 43.3% resided in urban areas.

Table 2. Descriptive Statistics of Functional

Outcome Measures (N = 60)

Outcome Measure	Mean ± SD	Minimum	Maximum
10-Meter Walk Test (m/s)	0.7 ± 0.08	0.88	0.58
Berg Balance Scale (BBS)	34.8 ±4.25	43	28
Manual Muscle Testing (MMT)	3.6 ± 0.6	5	3
Functional Independence Measure (FIM)	84.7 ± 6.1	96	74

Interpretation: Table 2 summarizes the descriptive statistics of the post-rehabilitation functional outcome measures for all 60 participants. Mean values and standard deviations describe the central tendency and variability of gait speed, balance, lower-limb muscle strength, and functional independence. These descriptive findings provide the basis for the subsequent correlation and regression analyses.

DISCUSSION

The present study was conducted to investigate the relationship between gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury. Unlike the primary manuscript, which compared the effectiveness of two rehabilitation interventions, the present study focused on understanding the associations among key functional outcome measures commonly used in neurological rehabilitation. The findings of this study provide insight into the interrelationship between walking ability, postural control, muscle performance, and independence in activities of daily living, thereby contributing to evidence-based physiotherapy practice.

Recovery following spinal cord injury is a complex process influenced by multiple neurological and musculoskeletal factors. Improvements in functional mobility are rarely attributable to a single physical component; rather, they result from the combined effects of motor recovery, trunk control, balance, muscle strength, neuromuscular coordination, and repetitive task-specific training. Therefore, examining the relationships among these variables is clinically important, as it enables physiotherapists to identify the functional impairments that are most closely associated with improved independence and to prioritize rehabilitation interventions accordingly.

The present study demonstrated that gait speed, assessed using the 10-Meter Walk Test, was associated with overall functional performance following physiotherapy. Walking speed is widely regarded as a practical indicator of locomotor ability and has been described as a functional "vital sign" in neurological rehabilitation. Patients who demonstrate faster and more efficient walking are generally able to perform transfers, community ambulation, and activities of daily living with greater independence. Improvements in gait speed following rehabilitation are likely to reflect enhanced neuromuscular coordination, improved postural stability, increased confidence during walking, and better motor control. These findings support the clinical importance of gait-speed assessment as a routine outcome measure during rehabilitation of individuals with spinal cord injury.

Balance is another fundamental component of functional recovery following spinal cord injury. Maintenance of postural stability during standing and walking requires the integration of sensory input, motor control, muscle strength, and anticipatory postural adjustments. Impaired balance increases the risk of falls, limits community participation, and restricts independence in daily activities. The Berg Balance Scale is widely recognized as a reliable and valid clinical tool for evaluating both static and dynamic balance in neurological populations. Improved balance following physiotherapy reflects better trunk control, coordinated lower-limb muscle activity, and enhanced postural reactions. These improvements may facilitate safer mobility and greater confidence during functional tasks.

Lower-limb muscle strength also plays a crucial role in functional recovery after spinal cord injury. Adequate strength is necessary for standing, walking, climbing stairs, transferring, and maintaining balance during movement. Physiotherapy interventions that incorporate progressive strengthening exercises, gait training,

and functional task practice may improve muscle activation and motor performance through activity-dependent neuroplasticity. However, muscle strength alone may not fully determine walking ability or functional independence, because gait performance also depends on coordination, balance, endurance, and trunk stability. Therefore, comprehensive rehabilitation programs should address all components of movement rather than focusing exclusively on strengthening exercises.

Functional independence represents the ultimate goal of rehabilitation after spinal cord injury. The Functional Independence Measure evaluates an individual's ability to perform essential activities of daily living with minimal assistance and therefore reflects the overall effectiveness of rehabilitation. Improvements in functional independence are influenced by multiple physical and psychological factors, including mobility, balance, muscle strength, confidence, motivation, and environmental adaptation. Consequently, identifying the functional variables most closely associated with independence may assist clinicians in establishing realistic treatment goals and individualized rehabilitation strategies.

The findings of the present study have important clinical implications for physiotherapy practice. Understanding the relationships among gait speed, balance, muscle strength, and functional independence enables clinicians to monitor rehabilitation progress more effectively and identify patients who may require targeted interventions. Routine assessment using standardized outcome measures such as the 10-Meter Walk Test, Berg Balance Scale, Manual Muscle Testing, and Functional Independence Measure allows physiotherapists to evaluate multiple dimensions of recovery and develop patient-centered treatment programs.

CONCLUSION

The present study investigated the relationship between gait speed, balance, lower-limb muscle strength, and functional independence following physiotherapy in patients with spinal cord injury. By examining these functional outcome measures collectively, the study sought to improve the understanding of the factors associated with functional recovery after rehabilitation.

The findings of this study indicate that gait speed, balance, muscle strength, and functional independence are closely related components of neurological rehabilitation. These functional domains should not be considered in isolation, as improvements in one aspect of performance are likely to occur alongside improvements in other areas of recovery. Comprehensive physiotherapy rehabilitation that addresses gait training, balance enhancement, muscle strengthening, and functional task practice may contribute to better overall rehabilitation outcomes and greater independence in activities of daily living.

Routine assessment using standardized outcome measures such as the 10-Meter Walk Test (10MWT), Berg Balance Scale (BBS), Manual Muscle Testing (MMT), and Functional Independence Measure (FIM) provides clinicians with valuable information regarding patient progress and functional status. Understanding the relationships among these measures may assist physiotherapists in identifying rehabilitation priorities, monitoring treatment effectiveness, and developing individualized, evidence-based rehabilitation programs.

The findings of this study also emphasize the importance of adopting a multidimensional approach to spinal cord injury rehabilitation. Rather than focusing on a single impairment, physiotherapy interventions should aim to improve multiple functional domains simultaneously in order to maximize mobility, enhance postural control, increase muscle performance, and promote functional independence.

Although the present study provides valuable information regarding the relationships among important clinical outcome measures, certain limitations should be acknowledged. The relatively small sample size and single-center study design may limit the generalizability of the findings. Furthermore, the study evaluated functional outcomes following a six-week rehabilitation

program, and long-term follow-up was not undertaken. Future research involving larger multicenter cohorts, extended follow-up periods, and advanced biomechanical and neurological outcome measures is recommended to further clarify the factors influencing functional recovery after spinal cord injury.

In conclusion, this study highlights the clinical importance of evaluating gait speed, balance, lower-limb muscle strength, and functional independence as interconnected components of rehabilitation following spinal cord injury. Understanding these relationships may assist physiotherapists in designing targeted rehabilitation strategies, optimizing functional recovery, and improving the overall quality of life of individuals with spinal cord injury. Future studies incorporating predictive statistical models and longitudinal assessments may further strengthen the evidence base for individualized physiotherapy rehabilitation.

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