



Effectiveness of gait training on functional mobility in individuals with incomplete spinal cord injury

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Abstract

Incomplete spinal cord injury (iSCI) can affect muscle strength, balance, walking ability, and overall functional mobility. These problems may reduce a person's independence and make daily activities more difficult. Gait training is an important part of neurological physiotherapy and is used to improve walking skills and functional movement after spinal cord injury. This paper examines the effectiveness of gait training in improving functional mobility in individuals with incomplete spinal cord injury based on findings from existing research. Different approaches, including overground walking, treadmill training, body-weight-supported training, task-specific gait practice, and technology-assisted methods, are considered. The review focuses on important outcomes such as walking speed, walking endurance, balance, gait performance, and functional independence. Previous studies suggest that regular and appropriately designed gait training can improve walking performance and functional mobility. However, the level of improvement may differ depending on the severity and characteristics of the injury, initial functional ability, training intensity, and duration of rehabilitation. Differences in training methods and outcome measures also make it difficult to compare results across studies. Overall, gait training appears to be a useful approach for improving functional mobility in individuals with incomplete spinal cord injury. Further research with consistent training protocols and reliable outcome measures is needed to identify the most effective approaches and understand their long-term benefits.

Keywords: Incomplete spinal cord injury, gait training; functional mobility, walking ability, neurological physiotherapy

Introduction

Spinal cord injury (SCI) is a serious neurological condition that can produce long-term changes in movement, sensation, balance, and physical independence. The World Health Organization (WHO) reports that more than 15 million people worldwide are living with spinal cord injury. Road traffic accidents, falls, and other traumatic events are among the important causes of SCI. Depending on the level and severity of the injury, individuals may experience complete or partial loss of motor and sensory functions below the affected area. The impact of SCI is not limited to physical impairment. Difficulties in mobility may also affect self-care, education, employment, social participation, and quality of life. Therefore, appropriate medical care, rehabilitation, assistive devices, and continuing health support are important for improving functional outcomes and independence.

Incomplete spinal cord injury (iSCI) is particularly important from a rehabilitation perspective because some motor or sensory function remains below the level of injury. However, the preservation of neurological function does not necessarily result in normal or independent walking. Individuals with iSCI may continue to experience lower-limb weakness, impaired motor control, altered muscle tone, poor coordination, balance difficulties, and abnormal gait patterns [1]. These problems may reduce walking speed and endurance and can make standing, transferring, indoor walking, and community mobility difficult. Consequently, recovery should be considered not only in terms of whether a person can walk, but also in terms of how safely,

efficiently, and independently the person can perform mobility-related activities.

Functional mobility is therefore an important area of neurological physiotherapy. It involves changing body positions, standing, transferring, walking, and moving safely during daily activities. In individuals with iSCI, reduced mobility may result from the combined effects of muscle weakness, impaired postural control, sensory changes, altered muscle tone, and limited opportunities for walking practice. Effective rehabilitation consequently requires more than improving walking speed. It should also address balance, endurance, coordination, motor control, and functional performance [2]. Physiotherapists need to assess these areas and develop rehabilitation programmes according to the individual's neurological condition, functional capacity, and rehabilitation goals.

Gait training is an important rehabilitation approach for individuals with walking difficulties following incomplete spinal cord injury. It involves planned and repeated practice of walking and related movements to improve motor control and functional walking ability. Depending on the individual's needs, training may include overground walking, treadmill training, body-weight-supported walking, task-specific gait practice, and technology-assisted methods. Repeated practice can help individuals develop better movement patterns and gradually tolerate greater functional demands. Gait training may also be combined with strengthening exercises, balance training, functional electrical stimulation, orthotic support, and appropriate walking aids [3].

Rehabilitation is also supported through international and national health policies. WHO recognizes rehabilitation as an important component of health care and emphasizes improving functioning and reducing disability. Its rehabilitation framework highlights access to quality services, trained professionals, appropriate resources, monitoring, and research. The WHO Package of Interventions for Rehabilitation also includes spinal cord injury within neurological rehabilitation. In India, the Rights of Persons with Disabilities (RPwD) Act, 2016 provides a legal framework for protecting the rights, participation, and inclusion of persons with disabilities. Initiatives such as the Scheme for Implementation of the Rights of Persons with Disabilities Act (SIPDA) and the Deendayal Divyangjan Rehabilitation Scheme (DDRS) further support accessibility and rehabilitation services^[4]. These measures emphasize that rehabilitation should contribute not only to physical improvement but also to greater participation in family, community, education, and employment.

In clinical practice, the effectiveness of gait training should be assessed through meaningful functional outcomes. Walking speed and endurance are important indicators, but they do not fully represent functional recovery. Balance, walking ability, transfers, and independence should also be considered. Measures such as the 10-Meter Walk Test (10MWT), 6-Minute Walk Test (6MWT), Timed Up and Go (TUG), Walking Index for Spinal Cord Injury II (WISCI II), Berg Balance Scale (BBS), and Spinal Cord Independence Measure (SCIM) can help assess different aspects of mobility and function^[5].

Although gait training has been widely investigated in individuals with incomplete spinal cord injury, important gaps remain. Studies differ in training methods, frequency, duration, intensity, and outcome measures, making comparison difficult. Many studies also focus mainly on walking speed or endurance, while broader functional mobility includes balance, transfers, safety, and independence. Factors such as injury severity, baseline walking ability, muscle strength, balance, time since injury, and training dose may also influence outcomes. Furthermore, improvements achieved under supervised rehabilitation may not always translate into long-term independent or community mobility^[6]. These issues support the need for a focused examination of the available evidence.

Therefore, the present paper examines the effectiveness of gait training on functional mobility in individuals with incomplete spinal cord injury. It considers the effects of different gait-training approaches on walking speed, endurance, balance, gait performance, and functional mobility, while also examining factors that may influence rehabilitation outcomes. The review aims to provide a clearer understanding of the clinical role of gait training in neurological physiotherapy and identify areas requiring further research.

Functional Mobility Impairments in Incomplete Spinal Cord Injury

Incomplete spinal cord injury (iSCI) can affect functional mobility to different degrees depending on the level and severity of neurological involvement. Although some motor and sensory functions are preserved below the injured area, individuals may still experience difficulties with movement, balance, coordination, and postural control. The extent of

these problems differs from person to person. Some individuals may be able to walk independently but with reduced efficiency, while others may need walking aids, orthoses, or assistance from another person. Identifying these limitations is important for selecting appropriate physiotherapy interventions and setting realistic rehabilitation goals.

Lower-Limb Muscle Weakness

Reduced strength in the lower limbs is a major contributor to mobility difficulties following iSCI. Weakness may affect the muscles around the hip, knee, and ankle, making activities such as standing, stepping, and walking more demanding. Limited muscle force can also affect the ability to control the body during turning, stopping, or walking over uneven ground^[7]. As a result, individuals may walk more slowly, use compensatory movement strategies, or depend on assistive devices to move safely.

Balance and Postural Control

Adequate balance and postural control are necessary for safe movement. After iSCI, weakness, sensory changes, and impaired neuromuscular control may make it difficult to maintain stability while sitting, standing, or walking. Challenges may become greater during activities that require reaching, turning, changing direction, or stepping over an obstacle. Poor balance can reduce movement confidence and may contribute to instability and an increased risk of falls^[8].

Changes in Gait Performance

Individuals with iSCI may demonstrate changes in their walking pattern, including slower walking speed, unequal step length, altered foot placement, or difficulty maintaining a consistent gait rhythm. Some people develop compensatory movements to manage weakness or reduced motor control. Such adaptations may increase the effort required for walking and reduce overall efficiency. Difficulties may become more noticeable when walking conditions change, such as when negotiating uneven surfaces, stairs, or crowded environments^[9].

Reduced Walking Endurance

Walking endurance may also be limited after incomplete spinal cord injury. Muscle weakness, inefficient movement patterns, reduced physical conditioning, and the greater energy demands of walking can contribute to early fatigue. A person may therefore be able to walk short distances but struggle to continue walking for longer periods. Reduced endurance can interfere with activities such as shopping, travelling, attending educational or occupational settings, and participating in community life^[10].

Spasticity and Changes in Muscle Tone

Changes in muscle tone, particularly spasticity, may further affect functional movement. Increased muscle activity can restrict joint movement, alter limb positioning, and make certain phases of walking more difficult. It may also interfere with smooth and coordinated movement between different stages of the gait cycle^[11]. The effect of spasticity varies among individuals and depends on factors such as the muscles affected and the severity of the neurological impairment.

Sensory and Motor Control Problems

Sensory changes can influence a person's awareness of limb position, pressure, and contact with the ground. Reduced proprioceptive information may make it harder to accurately control lower-limb movements and maintain stability. At the same time, impaired motor control can affect the timing, coordination, and smoothness of muscle activity during movement. The combined effect of sensory and motor deficits may therefore reduce the safety and efficiency of functional mobility ^[12].

Difficulties with Transfers and Daily Activities

Functional mobility is not limited to walking. Individuals with iSCI may also have difficulty moving from sitting to standing, transferring between a bed and chair, changing position, or getting into and out of a vehicle. These tasks require coordinated control of the trunk and lower limbs, adequate strength, and sufficient balance. Difficulty performing transfers can increase dependence on family members or caregivers and may reduce overall independence in daily life ^[13].

Community Mobility and Participation

Mobility difficulties may become more apparent outside the controlled environment of a rehabilitation facility. Stairs, uneven surfaces, longer distances, crowded places, and changes in environmental conditions can place additional demands on balance and walking ability. An individual who can walk independently during a clinical assessment may still experience difficulty moving safely and confidently within the community ^[14]. For this reason, functional rehabilitation should address the transfer of mobility skills from the clinic to everyday environments.

Gait Training Approaches in Incomplete Spinal Cord Injury

Gait rehabilitation is an important component of physiotherapy for individuals with incomplete spinal cord injury (iSCI) who retain some potential for improving or maintaining walking ability. The primary aim is to provide repeated, purposeful walking practice while addressing problems related to lower-limb strength, balance, coordination, motor control, and endurance ^[15]. The choice of intervention should be based on the individual's neurological condition, present walking ability, level of assistance required, and rehabilitation objectives. Different gait-training methods can be used separately or combined according to the person's clinical needs.

Overground Gait Training

Overground gait training involves practising walking on a stable surface, either independently or with assistance and appropriate walking devices. This method provides an opportunity to practise stepping under conditions that more closely resemble everyday walking. Depending on the individual's progress, the physiotherapist may gradually modify walking distance, speed, direction, and environmental demands. Canes, walkers, crutches, and orthotic devices may be incorporated when clinically indicated. Because the training takes place in a functional walking environment, it can help develop skills that are relevant to routine mobility and daily activities ^[16].

Treadmill Training

Treadmill training provides a structured setting for repeated walking practice at a controlled speed. The therapist can adjust the speed, duration, and overall workload according to the individual's tolerance and walking capacity. Repetitive stepping on the moving belt provides opportunities to practise the gait pattern while allowing the therapist to observe and modify movement when necessary. Treadmill training may be performed independently or combined with body-weight support depending on the person's balance, strength, and level of walking ability ^[17].

Body-Weight-Supported Treadmill Training

Body-weight-supported treadmill training is designed to reduce the amount of body weight that must be managed during walking practice. A harness and suspension system partially unload the individual while stepping is practised on the treadmill. This can be particularly useful for people who have difficulty maintaining upright posture, supporting their body weight, or controlling their steps during independent walking. As functional ability improves, the amount of external support can be progressively reduced to encourage greater participation in weight-bearing and walking ^[18].

Task-Specific Gait Training

Task-specific gait training emphasizes repeated practice of movements that have direct relevance to the individual's functional mobility. Depending on the person's goals, treatment may include practising gait initiation, repeated stepping, turning, obstacle negotiation, stair climbing, and walking at different speeds. The activities are selected according to the individual's functional requirements and can be progressed as performance improves. Increasing task complexity, distance, speed, or environmental demands can provide a gradual challenge while maintaining a focus on meaningful walking activities ^[19].

Functional Electrical Stimulation-Assisted Gait Training

Functional electrical stimulation (FES) can support gait by producing activation of selected muscles during specific phases of functional movement. In individuals with iSCI, stimulation may be applied to muscles involved in functions such as foot clearance and forward movement of the lower limb. FES can be integrated with active walking practice so that the stimulated muscle activity occurs in relation to the walking task ^[20]. Its application should be individualized according to the person's neurological status, available muscle response, functional needs, and clinical objectives.

Robotic and Technology-Assisted Gait Training

Advances in rehabilitation technology have expanded the options available for gait training following incomplete spinal cord injury. Robotic gait-training systems can assist with repetitive stepping and may provide controlled support during different parts of the gait cycle. The degree of assistance can often be modified according to the individual's ability and progress. Other technology-based approaches, such as sensor-based feedback and virtual or augmented rehabilitation environments, can provide additional information about movement and create opportunities for repeated practice ^[21]. These technologies should be viewed as supportive components of rehabilitation

and should not replace clinical assessment, therapist supervision, or individualized treatment planning.

Combined and Individualized Gait Training

No single gait-training method is suitable for every person with incomplete spinal cord injury. In clinical practice, different approaches may be combined to address changing functional needs. For example, treadmill or body-weight-supported training may initially be used to facilitate repeated stepping, followed by overground practice to develop walking skills in more functional environments. Other interventions, including strengthening exercises, balance training, stretching, FES, orthotic management, and appropriate walking aids, may be incorporated when required.

The progression of gait training should be guided by regular assessment of walking performance, balance, muscle strength, endurance, motor control, and safety. As the individual's capacity improves, the therapist can gradually increase the intensity, duration, distance, or complexity of walking activities. This individualized progression helps ensure that rehabilitation remains focused on meaningful mobility goals rather than applying an identical programme to all individuals with iSCI [22].

Effectiveness of Gait Training on Functional Mobility

Gait rehabilitation is an important component of physiotherapy for individuals with incomplete spinal cord injury (iSCI), particularly when some degree of walking ability is preserved. Functional mobility after iSCI can be affected by weakness, impaired balance, reduced coordination, altered sensation, and limited endurance. Gait training aims to address these problems through repeated and purposeful walking practice. Its effectiveness can be examined through several outcomes, including walking speed, walking endurance, balance, gait performance, transfers, and the ability to move safely in everyday environments [23]. Although improvements are commonly reported in walking-related abilities, the response to training can differ considerably between individuals.

Improvement in Walking Speed

Walking speed provides useful information about a person's ability to move efficiently and perform functional walking tasks. In individuals with iSCI, appropriately structured gait practice may help improve the initiation, control, and continuity of walking. Repeated stepping activities can promote better coordination of the lower limbs and more effective control throughout the gait cycle. An increase in walking speed may also improve the person's ability to complete daily activities and negotiate community environments. However, the extent of change is influenced by factors such as neurological impairment, initial walking capacity, muscle strength, and the intensity and progression of rehabilitation [24].

Improvement in Walking Endurance

Limited endurance is a frequent concern following incomplete spinal cord injury and may restrict participation in activities that require prolonged walking. Regular gait practice can gradually increase the duration and distance for which an individual is able to walk. This progressive exposure to walking activity may improve exercise tolerance and help manage fatigue during functional

mobility. The Six-Minute Walk Test (6MWT) is commonly used to assess walking endurance and can provide information about changes in functional walking capacity. Better endurance may support activities involving longer distances, including travelling, shopping, employment, education, and community participation [25].

Effects on Balance and Postural Control

Adequate balance and postural control are essential for safe and efficient walking. Following iSCI, muscle weakness, sensory changes, impaired coordination, and altered postural responses can reduce stability during standing and movement. Gait rehabilitation may provide repeated practice of weight transfer, stepping, turning, and controlled changes in body position [26]. These activities can challenge postural control in a functional context and may improve the ability to maintain stability while walking. Better balance can be particularly valuable when changing direction, negotiating obstacles, or adapting to changes in the walking environment. The Berg Balance Scale (BBS) may be used to evaluate balance-related changes during rehabilitation.

Effects on Overall Functional Mobility

The influence of gait training extends beyond improvements in walking distance or speed. Better control of the lower limbs and trunk during walking may also support functional activities such as rising from a chair, transferring between surfaces, and moving independently around the home. Measures such as the Timed Up and Go (TUG) and the Spinal Cord Independence Measure (SCIM) can provide broader information about mobility and functional independence. Importantly, improvement on an individual walking test should not automatically be interpreted as complete functional recovery. A person may demonstrate satisfactory performance in a controlled clinical setting while still experiencing difficulty with stairs, uneven surfaces, crowded environments, or longer-distance community walking [27].

Influence of Training Characteristics

The outcomes of gait rehabilitation can be affected by how the training programme is designed and progressed. Factors such as frequency, duration, intensity, amount of assistance, task specificity, and gradual increases in difficulty may influence the response to treatment. Repeated practice should provide an appropriate level of challenge without causing excessive fatigue or compromising movement quality. As walking control improves, reducing external assistance may encourage greater active participation [28]. Therefore, the training programme should be regularly reviewed and adjusted according to the individual's performance and tolerance.

Individual Factors Affecting Outcomes

People with incomplete spinal cord injury do not respond to gait training in an identical manner. Recovery and functional improvement may be influenced by the neurological level and severity of injury, preserved motor function, sensory impairment, muscle strength, spasticity, balance, age, physical fitness, and other health conditions. Initial walking ability is also an important consideration because individuals with different baseline abilities may have different rehabilitation potential and treatment needs. In addition, motivation, psychological readiness, access to

rehabilitation services, and the appropriate use of walking aids may influence participation and functional progress ^[29].

Clinical Interpretation of Effectiveness

The effectiveness of gait training should be evaluated using a combination of outcome measures rather than relying on a single indicator of walking performance. An improvement in walking speed, for example, may not necessarily be accompanied by similar gains in endurance, balance, or community mobility. A comprehensive assessment should therefore consider both changes in physical impairments and improvements in practical activities. Safe walking, independent transfers, the ability to manage environmental challenges, and participation in home and community activities provides a broader understanding of meaningful functional recovery ^[30].

Outcome Measures and Clinical Assessment

Assessment plays a central role in rehabilitation for people with incomplete spinal cord injury (iSCI). Standardized clinical tools enable physiotherapists to establish a starting level of functional performance, identify mobility limitations, and track changes during treatment. They also help determine whether improvements in walking translate into greater independence in daily activities. Since iSCI can influence several components of mobility, including gait speed, endurance, balance, transfers, and walking independence, using a combination of complementary measures gives a more complete picture of functional progress ^[31].

10-Meter Walk Test

The 10-Meter Walk Test (10MWT) is a simple measure used to determine walking speed. The individual walks a defined distance, and the time required to complete the test is recorded to calculate walking velocity. Repeated testing can help identify changes in walking performance following rehabilitation. It is particularly useful when monitoring short-distance gait ability. However, the relatively short testing distance means that it cannot provide a complete assessment of sustained walking capacity or resistance to fatigue ^[32].

Six-Minute Walk Test

The Six-Minute Walk Test (6MWT) is primarily used to examine walking endurance. It records the distance that a person is able to cover during a six-minute period and therefore provides information about sustained functional walking capacity. It can be useful for identifying changes in endurance and the effect of fatigue on walking performance. Test results, however, may be affected by several factors, including the individual's motivation, physical condition, fatigue, cardiovascular tolerance, initial walking ability, and use of mobility aids ^[33].

Timed Up and Go Test

The Timed Up and Go (TUG) test examines functional movement through a sequence of activities rather than straight walking alone. The individual rises from a chair, walks a predetermined distance, turns, walks back, and returns to a seated position while the completion time is recorded. The test provides information about mobility, balance, transitional movements, and walking control. Its performance can be influenced by lower-limb strength,

postural stability, coordination, and the type of walking assistance used by the individual.

Berg Balance Scale

The Berg Balance Scale (BBS) is used to examine functional balance through several activities involving sitting, standing, and transfers, reaching, turning, and maintaining different body positions. Assessment of balance is particularly relevant in iSCI because impaired postural control may compromise safe walking and functional movement. Changes in BBS performance can help clinicians monitor balance-related progress during rehabilitation. Nevertheless, performance during structured testing may not fully reflect the balance challenges encountered in unpredictable community environments.

Walking Index for Spinal Cord Injury II

The Walking Index for Spinal Cord Injury II (WISCI II) is a spinal cord injury-specific measure that evaluates the level of assistance required for walking. It also considers the use of walking aids and orthotic devices during the assessment. The measure can be particularly useful for documenting changes in walking independence as rehabilitation progresses. However, its main emphasis is on assistance and equipment requirements, so it provides less information about walking endurance, environmental adaptability, and participation in community activities ^[34].

Spinal Cord Independence Measure

The Spinal Cord Independence Measure (SCIM) is designed to evaluate functional independence in people with spinal cord injury. It covers multiple areas, including self-care, respiratory and sphincter-related functions, and mobility. The mobility domain is especially relevant when examining functional movement and transfers. SCIM therefore adds a broader functional perspective to gait-specific tests and can help determine whether improvements in mobility are associated with greater independence in everyday life ^[35].

Clinical Assessment and Interpretation

The selection of outcome measures should reflect the individual's neurological condition, current functional capacity, rehabilitation objectives, and stage of recovery. A baseline assessment followed by periodic reassessment allows clinicians to identify changes over time and modify the rehabilitation programme when necessary. Assessment findings should be considered collectively rather than interpreting a single test as evidence of overall recovery. For instance, a person may demonstrate faster walking while continuing to have poor endurance or balance. Similarly, improved performance in a controlled clinical environment may not automatically translate into safe mobility on stairs, uneven ground, crowded pathways, or during longer community journeys.

Conclusion

Restoring walking ability and improving functional mobility remain important objectives in the rehabilitation of individuals with incomplete spinal cord injury (iSCI). This review considered the nature of mobility limitations following iSCI, the different approaches used in gait rehabilitation, their potential clinical benefits, and the tools available for assessing treatment outcomes. The literature discussed suggests that gait training may support progress in

walking speed, endurance, balance, and movement control. However, the outcomes achieved are not uniform and may depend on the extent of neurological impairment, the motor functions retained after injury, the individual's initial walking capacity, and the design of the rehabilitation programme.

Conventional and technology-supported interventions provide several options for gait rehabilitation. Overground walking, treadmill-based practice, body-weight-supported training, task-oriented activities, functional electrical stimulation, and robotic or other technology-assisted methods can be selected according to individual requirements. Treatment decisions should consider functional goals, physical capacity, safety, and progress during rehabilitation rather than relying on a single approach for all patients. Assessment should also extend beyond walking speed and distance to include balance, transfers, walking independence, and the ability to negotiate everyday environments. Using complementary instruments, including the 10-Meter Walk Test, Six-Minute Walk Test, Timed Up and Go test, Berg Balance Scale, Walking Index for Spinal Cord Injury II, and Spinal Cord Independence Measure, can help identify different dimensions of functional change.

Several methodological concerns remain within the available research. Differences in intervention delivery, training intensity, assessment procedures, and follow-up duration make it challenging to compare findings across studies and identify the most beneficial rehabilitation strategies. In addition, improvements recorded during supervised sessions may not fully reflect a person's ability to maintain independence or participate in community activities over the longer term. These limitations underline the need to interpret reported outcomes carefully and distinguish short-term changes from sustained functional benefits.

From a clinical perspective, gait rehabilitation should be individualized, progressively adjusted, and directed towards practical mobility goals. Future investigations should include rigorous comparative designs, clearly reported training protocols, appropriate combinations of outcome measures, and extended follow-up to examine the durability of treatment effects. The overall implication is that successful gait rehabilitation should be judged not merely by improved walking performance, but also by whether these gains translate into safer movement, greater functional independence, and more active participation in daily life. Further research is necessary to establish which interventions are most suitable for different groups of individuals with iSCI and how their benefits can be maintained beyond supervised rehabilitation.

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