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# Spinal Cord Injury Therapy Review

# Physiotherapy Rehabilitation for People With Spinal Cord Injuries

KEY WORDS

Rehabilitation
Spinal cord injury
Physical therapy

## Introduction

The most obvious consequence of spinal cord injury (SCI) is paralysis. However, SCI also has widespread consequences for many body functions, including bladder, bowel, respiratory, cardiovascular and sexual function. It also has social, financial and psychological implications, and increases people's susceptibility to late-life renal complications as well as musculoskeletal injuries, pain, osteoporosis and other problems.

People with SCI require not only initial medical care and rehabilitation, but also ongoing access to wheelchair-friendly environments and appropriate homecare, equipment, transport, employment and financial support. The management of people with SCI is therefore complex, involving many healthcare professionals, organisations and government services. Physiotherapists treat an array of different problems related to SCI and these involve many body systems, even though the underlying pathology is neurological in nature.

This review outlines the principles of physiotherapy rehabilitation for people with SCI and the evidence underpinning the effectiveness of commonly used physiotherapy interventions. It focuses on three common problems: weakness, contractures and poor motor control. Only the rehabilitation phase is discussed here, although physiotherapists also have an important role to play immediately after injury and in the community once patients are discharged from hospital.

## Types of spinal cord injuries

Spinal cord injuries are defined as complete or incomplete according to the International Standards for the Neurological Classification of SCI[1] and the American Spinal Injuries Association Impairment Scale (AIS). Complete lesions are defined as AIS A, and incomplete lesions are defined as AIS B, AIS C, AIS D or AIS E. This classification system was introduced in 1982 to replace the original, but perhaps more intuitive, Frankel system whereby a person was classified as having an incomplete SCI if they had any motor or sensory preservation more than three levels below the level of injury. In contrast, the International Standards for the Neurological Classification of SCI[1] distinguishes between complete and incomplete injuries on the basis of sensory and motor preservation in the S4/5 segments. A lesion is classified as complete if a person has no voluntary anal contraction (indicative of S4/5 motor preservation) and/or sensation in or around the anus (indicative of S4/5 sensory preservation), regardless of how much motor or sensory function they have below the level of the lesion. The distinction between different types of incomplete lesions is based on a detailed motor and sensory assessment. The precise definitions of different types of SCIs are surprisingly complex and contain ambiguities that continue to be debated.

## Principles of management

Acute medical management of people with SCI focuses on minimising further neurological damage to the spinal cord and optimising recovery. Stability of the spine is clearly a priority. This is established either conservatively with bed rest (with or without traction) or surgically (typically with decompression and fusion). While surgical management is now more common than conservative management, there is still a lot of debate about the superiority of each approach. However, management of the spine is just one aspect of acute medical care. There are many other aspects related to maintaining blood pressure, circulation, respiration, bladder drainage, bowel care, nutrition and body temperature, and minimising psychological distress for patients and their families. During this stage, physiotherapy is predominantly focused on treating respiratory complications and preventing secondary musculoskeletal problems related to prolonged bed rest. Readers interested in the physiotherapy management of people in the period immediately after injury are directed to the official textbook[2] or online learning modules (www.elearnSCI.org)[3] of the International Spinal Cord Society.

Rehabilitation following SCI commences as soon as the patient is medically stable after injury. This can vary from a few days to many weeks, depending on whether the patient suffered other injuries at the time of the accident or subsequently developed medical or respiratory complications. Rehabilitation involves a team and patient-centred approach. The overall aim of rehabilitation is to enable the person to return to a productive and satisfying life. This means different things to different people. For example, some people place a high priority on independence and/or walking, while others do not. Studies have attempted to identify the priorities of people with SCI, although none have used representative samples and therefore all need to be interpreted with caution. A widely cited study from a sample of over 650 people in the USA found that those with tetraplegia placed the highest priority on regaining hand and upper limb function, and those with paraplegia ranked return of sexual function as their most important priority.[4] Regaining the ability to walk was also a high priority for both groups of people but, contrary to what is often assumed, it was not the highest priority.

Physiotherapy during the rehabilitation phase focuses on goals related to motor tasks such as walking, pushing a wheelchair, transferring and using the upper limbs.[5] The setting of goals for a person with SCI is fraught with difficulties because it relies, at least in part, on physiotherapists' and patients' predictions of likely outcomes. Much has been written about likely outcomes (see the paper by Scivoletto and Di Donna for a summary)[6] but the best estimates of outcome come from a European cohort study in which data were collected within 15 days of traumatic SCI and then 1 year later.[7] Unfortunately, data were only available for 492 of the original 1282 eligible patients, thereby limiting the confidence in the derived prediction rule. Nonetheless, the results indicated that the ability to walk at 1 year is best predicted from five variables collected within 15 days of injury: age, quadriceps strength, gastrocnemius strength, light touch sensation at L3 and light touch sensation at S1 (area under the curve (AUC) 0.956, 95% CI 0.936 to 0.976). There are other studies based on large databases looking at factors predicting outcomes other than walking, but they are less rigorous and invariably do not reflect the population at large.

A recent study examined physiotherapists' ability to predict the likelihood of patients walking (and performing an array of other motor tasks) at 3 months[8] and then 1 year from injury;[9,10] this was based on physiotherapists' assessments of patients at the time of admission to rehabilitation. The predictions were made a median of 45 days (IQR 31 to 73) after injury. Importantly, 50 of the potentially eligible 67 participants were included in the analysis. The results of this study indicated that physiotherapists were good at predicting the likelihood of walking at 1 year. The positive likelihood ratio associated with predictions of walking around the home at 1 year was 5.7 (95% CI 2.3 to 14.4) and the negative likelihood ratio was 0.2 (95% CI 0.1 to 0.5). Patients were also asked to predict their own future mobility. Interestingly, but perhaps unsurprisingly, there was an obvious discord between patients' expectations of walking and final mobility, with patients expecting to attain a higher level of mobility than the mobility predicted by their physiotherapists. The authors have since hypothesised that this discord may, in part, be due to the recent tendency of the media to encourage the public to believe that recovery and walking is now a realistic outcome for all people with SCI regardless of the severity of the injury.[10–12] This is clearly not the case and physiotherapists need to play their role in educating the media on this issue.

## Assessment

The assessment of a patient with SCI is an important initial step in physiotherapy management. This step is not only important for setting realistic goals, but also for identifying key problems. Often, assessments conducted for this purpose are subjective. For example, a physiotherapist may subjectively assess a patient's ability to transfer from a wheelchair to a bed in an attempt to identify any underlying problems. The assessment may involve watching and analysing a patient's attempts at transferring, in order to determine which part of the transfer the patient is having difficulties performing and to isolate the underlying problems. This type of assessment helps to guide treatment.

Assessments are also used to provide an objective way of monitoring improvement over time. More standardised and objective assessments are required for this purpose. So, rather than observing a patient's attempts at a transfer, a therapist may quantify the amount of assistance the patient requires to transfer or measure the time taken to transfer using a standardised assessment that captures these constructs. Of course, some standardised and objective assessments can also be used to identify underlying problems and guide treatment, particularly assessments of impairments.

Standardised assessments of impairments are similar to those used across all areas of physiotherapy, although there are some that are specific to SCI. For example, assessments of sensation are performed according to the International Standards for Neurological Classification of SCI and are specific to SCI.[13] In this assessment, only one precise spot is tested to represent each dermatome. So to determine if the C6 dermatome is intact, a very small and precise spot is tested on the dorsal aspect of the thumb just distal to the metacarpophalangeal joint. Light touch and pinprick are separately scored on a 3-point scale, where a score of 0 reflects no sensation, a score of 1 reflects altered sensation and a score of 2 reflects normal sensation. The sensation of all 56 dermatomes needs to be compared with sensation on the face for both light touch and pinprick. The test is therefore very time-consuming. Studies have reported reasonable reliability of the sensory tests with better reliability for the light touch test than the pinprick test.[14,15]

Assessments of impairments are of limited interest to a physiotherapist without accompanying assessments of activity limitations to quantify a person's ability to move and complete purposeful motor tasks. There are just as many different standardised assessments of activity limitations as there are assessments of impairments, and again some are generic assessments while others are specific to SCI. The most commonly used assessments that are specific to SCI and physiotherapy include the Spinal Cord Independence Measure (SCIM)[16,17] and the Walking Index for SCI (WISCI).[18] The SCIM is equivalent to the Functional Independence Measure and provides a score out of 100 to reflect a person's ability to live and move independently.[19] It includes items that address a person's ability to transfer, walk, dress, feed, breathe and maintain bladder and bowel continence. There is a self-report version of the SCIM that has good reliability and is simple to administer.[20] The WISCI is a 21-point scale that summarises a person's ability to walk after taking into account need for assistance, orthoses or walking aids.[21] The WISCI also includes a 10-m timed walk test. Both the SCIM[19] and WISCI[21] have problems with their scoring algorithms, but nonetheless they are widely used in most SCI units around the world.

Despite the obvious importance of assessments for physiotherapists, there is no general international consensus on the most appropriate battery of physiotherapy-specific assessments.[22] However, representatives of the Spinal Cord Injury Group of the American Physical Therapy Association have put together a list of their recommendations,[23] and the international SCI community has developed basic datasets for people with SCI.[24] Some of the basic datasets are relevant to physiotherapists[25,26] and include assessments that could be used to both guide treatment and monitor improvements over time [illegible]

## Physiotherapy interventions

The results of the assessment and goal-setting process are used to guide treatment. Clearly, treatments need to be based on evidence, but this poses a real challenge for the physiotherapy profession because of the surprisingly few high-quality and conclusive randomised, controlled trials involving people with SCI.[27] A recent count put the number of clinical trials at approximately 60 (excluding trials designed to determine the effectiveness of interventions for respiratory function or trials involving education or the provision of mobility-related equipment).[28] Most of these trials have been conducted in recent years and focused on interventions such as treadmill walking with overhead suspension, robotic gait training, electrical stimulation and other high-technology and potentially costly interventions. Interestingly, an audit of three typical SCI units in Europe and one in Australia indicated that therapists still devote most of their time to administering simpler interventions commonly used to treat impairments such as weakness, limited joint mobility, restricted fitness, pain and respiratory compromise, with time also being devoted to teaching people to walk, move about the bed, mobilise in a wheelchair and use their upper limbs.[29] This situation indicates a disconnect between researchers' priorities and the treatments provided by clinicians. This does not mean that clinicians are not providing optimal or appropriate treatments, but it does mean that the treatments clinicians are providing are not always based on high-quality clinical trials involving people with SCI and that researchers are not always testing the effectiveness of the treatments commonly administered by clinicians.

In the absence of high-quality trials involving people with SCI to guide treatment, physiotherapists need to look further afield and be guided by what is known from other areas of physiotherapy. The results of high-quality trials in other patient groups may often provide more accurate evidence about likely responses of people with SCI to treatments than looking at non-randomised or poorly conducted trials in people with SCI; both of which often provide biased estimates of treatment effects.[30] In addition, physiotherapists need to be guided by a logical problem-solving approach to treatment selection. For example, if a person with C6 tetraplegia wants to learn to transfer independently from a wheelchair to a bed, they need to be taught how to do this and the physiotherapist needs to understand the biomechanics of appropriate movement strategies. Clinical trials involving people with C6 tetraplegia learning to transfer are probably not required to guide treatment decisions. Instead, physiotherapists can apply what is known about the biomechanics of moving with C6 tetraplegia and the principles of effective teaching of motor skills.

One of the challenges for physiotherapists working in SCI is not only the lack of high-quality direct evidence but also the extensive scope of practice. For example, physiotherapists working in SCI: treat pain and respiratory complications; use electrical stimulation to treat pressure ulcers; formulate fitness training programs; encourage people with SCI to adopt healthy lifestyles; teach disabled sports; provide patients with various types of orthoses, splints and aids; prescribe wheelchairs; advise on strategies to prevent shoulder pain and pressure ulcers; and administer various electrotherapeutic interventions. Consequently, physiotherapists treating people with SCI need diverse clinical skills. The other challenge for physiotherapists working in this area is maintaining an open mind about new interventions such as stem cell therapy and robotics, while resisting the temptation to embrace these interventions until high-quality evidence proves their effectiveness. New interventions should not be rolled out on the basis of low-quality evidence, because they may waste time, money, resources and patients' efforts, and they may give patients an unrealistic expectation of recovery.[11] In addition, they quickly become entrenched as standard practice, particularly if they involve commercial interests and people with SCI perceive them to be beneficial. Once these interventions are rolled out, a window of opportunity closes to scrutinise these interventions within clinical trials.

The following paragraphs focus on three key problems: weakness, contractures and poor motor control. No attempt is made to review the full scope of physiotherapy practice in SCI. Readers interested in learning more about all aspects of physiotherapy management are directed elsewhere.[2,3,5]

### *Physiotherapy interventions to increase strength*

Weakness is the most obvious impairment that prevents people with SCI from performing motor tasks. Consequently, strength training interventions are widely administered by physiotherapists.[31] Limited strength in people with SCI can be neurologically

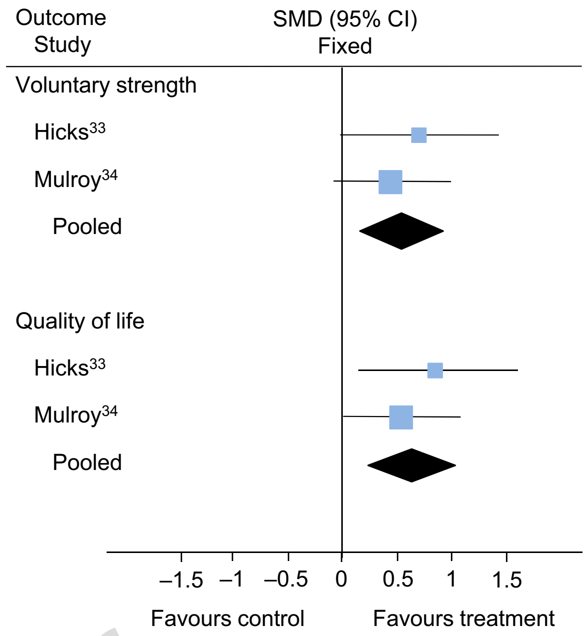


**Figure 1.** Standardised mean difference (SMD) of the effect of progressive resistance training versus control on voluntary strength of non-paralysed muscles and quality of life in people with SCI.

induced, as seen in people with Grade 2 or 3 strength in the quadriceps muscle who are trying to walk. Alternatively, limited strength may be due to insufficient muscle mass (or, more accurately, insufficient physiological cross-sectional area) in neurally intact muscles such as the upper limb muscles of people with paraplegia trying to master a floor-to-wheelchair transfer.

There is no reason to believe that the neurologically intact muscles of a person with SCI would respond to strength training any differently than the muscles of an able-bodied person. So for example, the appropriate upper limb strength training program for a person with paraplegia aimed at improving the ability to lift from the floor to a wheelchair needs to follow the same principles of strength training as would be applied to an able-bodied person. That is, the person requires a progressive resistance training program in which the load is appropriately and progressively increased. Such training is often best performed within the context of a functional skill, provided the principles of progressive resistance training can be maintained. There are many clinical trials in able-bodied people to guide evidence-based practice in this area.[32] In addition, two clinical trials[33,34] involving 92 participants with SCI have demonstrated that progressive resistance training for non-paralysed muscles not only increases strength but also increases quality of life (see Figure 1).

The situation is not so clear with partially paralysed muscles directly affected by SCI. There is strong evidence to indicate that people with partial paralysis following SCI get stronger with time. This evidence comes from longitudinal studies,[35] which show changes in strength and neurological status with accompanying changes in function. In addition, the within-group changes of clinical trials and non-randomised studies all consistently point to increases in strength of partially paralysed muscles over time. It is generally assumed that these increases are due to a combination of central and peripheral factors. The peripheral factors include muscle hypertrophy, and the central factors include neural adaptations either at the site of the injured spinal cord or even possibly within the brain. It is unclear how much of the observed increases in strength of partially paralysed muscles can be attributed to physiotherapy interventions as opposed to natural recovery.

The optimal training paradigm to increase strength in partially paralysed muscles is unclear. In particular, it is unclear whether strength is best improved by applying the principles of progressive resistance training or by focusing on high repetitions with limited

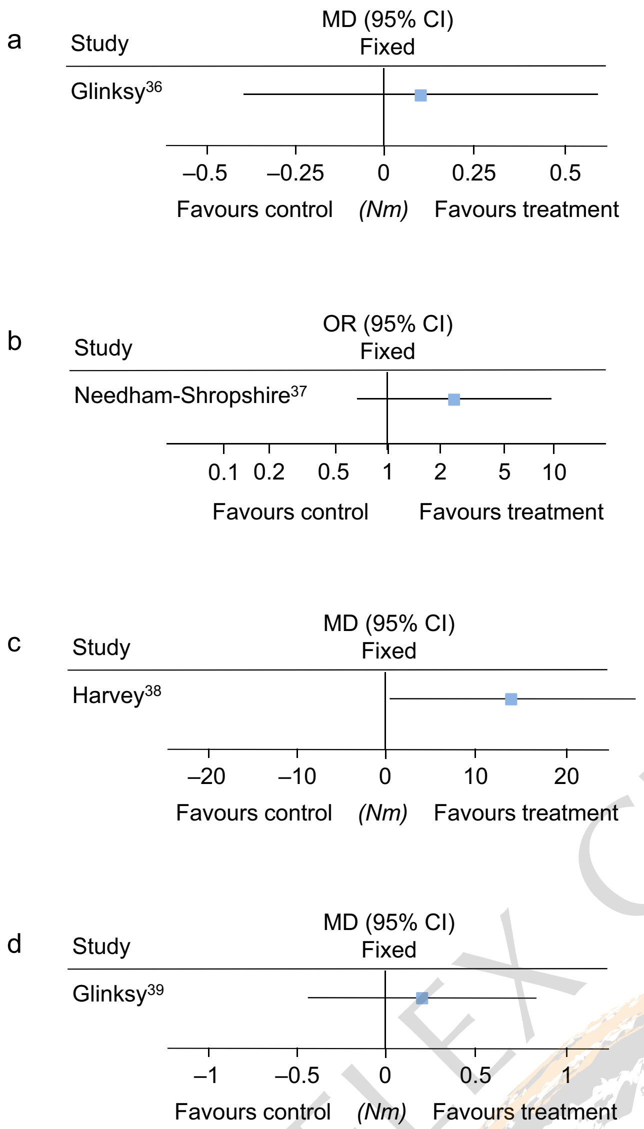


**Figure 2.** (a) Mean difference (MD) of the effect of electrical stimulation versus control on torque of partially paralysed muscles in people with SCI. (b) Odds ratio (OR) of the effect of electrical stimulation versus control on upper limb American Spinal Injuries Association Impairment Scale A (AIS A) motor score of partially paralysed muscles in people with SCI. (c) Mean difference (MD) of the effect of electrical stimulation and progressive resistance training versus control on torque of partially paralysed muscles in people with SCI. (d) Mean difference (MD) of the effect of progressive resistance training versus control on torque of partially paralysed muscles in people with SCI.

resistance. It is also unclear whether strength training programs are enhanced by electrical stimulation.

Four randomised, controlled trials[36–39] have specifically looked at the effectiveness of progressive resistance training and electrical stimulation or a combination of the two interventions. They have conflicting results (see Figure 2). The most promising results come from a trial[38] of an 8-week strength training program comprising progressive resistance training and electrical stimulation compared with no intervention for the partially paralysed quadriceps muscles of people with SCI (mean between-group difference 14 Nm, 95% CI 1 to 27). The estimate of the treatment effect was imprecise but nonetheless indicates a potentially clinically important increase in strength. The results of the other three trials investigating different combinations of progressive resistance training and electrical stimulation in very weak muscles give less grounds for optimism.[36,37,39] One of these trials involved electrical stimulation and arm ergometry with resistance[37] but it is unclear whether the principles of progressive resistance training (particularly the use of high resistance) were strictly adhered to.

Another eight trials[40–47] have examined the effect of some type of low load and repetitive practice on the strength of partially paralysed muscles of the upper or lower limbs: two in the upper limbs and six in the lower limbs. The interventions in these trials included robotic gait training, overhead gait training, intensive hand practice with sensory stimulation, and various combinations of these. Importantly, all of the interventions involved high repetitions so, whether stated or not, the interventions did not include high loads typical of progressive resistance training. Most of the trials measured strength using manual muscle testing to derive an overall motor score. Importantly, therefore, these scores largely reflect increases in strength of partially paralysed muscles and not increases in strength of neurally intact muscles. Interestingly, only two of these trials indicated a treatment effect on strength.[40,47] The first trial compared robotic gait training with overground gait training[40] (MD 5 points on a 50-point scale, 95% CI 2 to 9) and the second trial compared intensive hand training with no training (between-group differences were not provided and are not calculable).[47] The latter trial measured hand strength with a pinch meter, which may reflect changes in strength of the non-paralysed wrist extensor muscles of some participants, so the results may not be indicative solely of changes in strength of partially paralysed hand muscles.[47] In addition, it was the only trial to include a control group that received no intervention. The other trials compared different types of interventions.

Taken together, this evidence indicates how little is known about the response of partially paralysed muscles to different strength training paradigms. In the absence of clear guidance, the most sensible approach may involve a combination of progressive resistance training interspersed with repetitive practice of functional tasks involving low loads and high repetitions. It may also be reasonable to administer electrical stimulation in combination with high resistance and maximal voluntary effort. However, there is little evidence to suggest that electrical stimulation alone will increase voluntary strength,[36,48] although it may be therapeutic for other purposes, including minimising atrophy in paralysed muscles,[49] preventing secondary peripheral nerve deterioration,[50] encouraging neural repair[51] and promoting healing of pressure ulcers.[52] Unfortunately there are no large high-quality trials involving electrical stimulation for any of these purposes, so there are no unbiased estimates of its possible therapeutic effects.

### *Physiotherapy interventions to treat and prevent contractures*

Contractures are a common problem after SCI. At least two cohort studies have followed representative samples of people with SCI over a 1-year period in an attempt to quantify the extent of the problem. One study indicated that 66% (95% CI 55 to 77) of people who sustain a SCI will have at least one notable contracture within a year of injury,[53] and the other study indicated that 70% (95% CI 57 to 81) of people with tetraplegia will have loss of shoulder range of motion 1 year after commencing rehabilitation.[54] No study has followed patients for more than 1 year, but anecdotal evidence suggests that contractures become increasingly problematic, with some patients developing severe contractures.

Passive movements and stretch are widely used to treat and prevent contractures. However, uncertainty remains about whether these interventions are effective. Three clinical trials with useable data have examined the effect of stretch, and one trial has examined the effect of passive movements on joint mobility in people with SCI (see Figure 3). Pooling the results of the three stretch trials gives a mean between-group difference of 2 deg (95% CI 1 to 4). These results are consistent with a meta-analysis of 25 trials involving 812 participants with all types of neurological conditions (mean pooled between-group difference 1 deg, 95% CI 0 to 3).[55,56] They are also similar to the results of the one trial on passive movements.[57] Together they indicate the possibility of a very small treatment effect that most would not consider to be

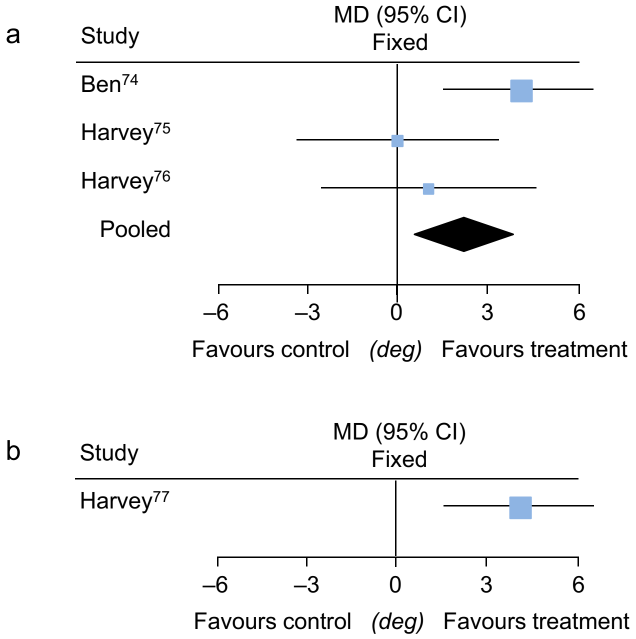


**Figure 3.** Mean difference (MD) of the effect of (a) stretch and (b) passive movements versus control on joint range of motion in people with SCI.

clinically worthwhile. However, there is a difficulty with the interpretation of these data because none of these studies provided stretch or passive movements for more than 6 months, and most only provided stretch or passive movements for between 4 weeks and 3 months. Therefore, the effectiveness of stretch or passive movements administered every day over very long periods is unknown, although stretch and passive movements are often provided over the course of a person's life. Even a 1-deg benefit every 6 months would transpire to a 40-deg benefit after 20 years. Of course, it cannot be assumed that treatment effects accumulate over time, but nor can this possibility be dismissed. It is also unknown how long stretches need to be maintained each day or how many times a joint needs to be passively moved. In all trials to date, the stretches and passive movements were administered in very large dosages that are not typically administered in clinical practice. Therefore, many uncertainties remain, although it would seem that we can only hope to have an effect if stretches and passive movements are administered in high doses and over long periods of time.

If stretches and passive movements are to be administered in high doses and over long periods of time then they need to be part of people's daily regimens. That is, passive movements need to be self-administered as far as possible, and stretches need to be incorporated into an appropriate positioning program. However, this can be time-consuming for people with SCI, so clinicians need to prioritise attention to where contractures are most likely to occur and to where contractures are likely to have profound effects on quality of life. Therefore, physiotherapists require skills in predicting contractures and their implications for each person.[58] For example, people with C6 tetraplegia are highly vulnerable to elbow flexion contractures because they have paralysis of the triceps muscles. Even slight loss of elbow extension will prevent a person with C6 tetraplegia from lifting his/her bodyweight through the upper limbs. The inability to lift renders a person incapable of transferring and, hence, dependent on others. This has major implications on quality of life. Therefore, preventing elbow flexion contractures in people with C6 tetraplegia should be a high priority and patients should be educated about appropriate positioning programs for the elbow (eg, sleeping with the elbows extended). This may take priority over other joints and soft tissue structures. It is possible to use similar clinical reasoning to prioritise contracture management programs for people with all types of SCI.[58] However, the emphasis for contracture management needs to be on simple and sustainable strategies that do not require large time commitments from people with SCI. Readers are directed to www.physiotherapyexercises.com for practical home stretching regimens for people with different types of SCI.

### *Physiotherapy interventions to improve the performance of motor tasks*

Much of physiotherapy is directed at improving patients' abilities to perform motor tasks such as walking, transferring, pushing a wheelchair and using the upper limbs. Therapy is typically based on principles of motor learning. For example, if a person with motor complete T4 paraplegia wishes to learn to transfer from a seated position, then he/she will learn best with repetitive practice that incorporates part practice along with appropriate use of instructions, feedback and manual guidance.[59] But of course there are many subtleties involved with applying these learning principles in an effective way for people with SCI. Evidence about the effectiveness of these training strategies is unlikely to come from clinical trials in people with SCI. Instead we need to rely on theories of motor control built on the findings of experiments and randomised trials in similar patient and able-bodied populations.

The principles of motor learning can also be used to train gait in people with the potential to walk. Again, repetitive practice is a key component. If a patient has extensive paralysis and the goal is to walk with orthoses and walking aids, then the patient needs to practise walking with orthoses and walking aids. In contrast, if a patient has potential for neurological recovery and the goal is to walk as an able-bodied person, then the patient needs to practise walking as closely as possible to an able-bodied person. Treadmills and robotic devices can be used to make gait training easier and to provide an opportunity for intensive repetitive practice using a gait strategy that mimics that of an able-bodied person. This is clearly a good development. There are, however, two controversial and unresolved issues related to the use of these devices. Firstly, who has the potential for neurological recovery and secondly, is treadmill and robotic training inherently superior to overground training?

The evidence about the superiority of treadmill training and robotic devices compared with overground training comes from animal studies, some of which date back to the 1980s and show therapeutic effects of cyclic walking.[60] It is believed that cyclic walking promotes neural plasticity within the spinal cord and the 'training' of central pattern generators; a complex reflex of the spinal cord.[51,61,62] Non-randomised trials, single case studies or studies using historical controls also suggest that these treatments are therapeutic, particularly in those with motor incomplete lesions.[63] However, clinical trials have failed to replicate these promising results. Figure 4 shows the results of the six randomised, controlled trials involving 263 participants comparing treadmill training with overground training.[42–46,64] The pooled mean between-group difference for gait velocity was –0.01 m/s (95% CI –0.09 to 0.08). These results are equivalent to those of a 2012 Cochrane review[65] (which does not include a recent trial)[64] and to the results of two clinical trials comparing robotic gait training with overground gait training (see Figure 5).[40,46] These findings also parallel the results of similar trials in stroke[66] and other neurological conditions, all pointing to the conclusion that gait training in these devices is not superior to overground gait training, provided patients have the opportunity for repetitive practice. This has prompted a rethink of beliefs and assumptions, and is the source of considerable controversy.[12,67] It suggests that there is nothing intrinsically therapeutic about cyclic walking on treadmills or with robotic devices, although both may provide a convenient and safe way for therapists to provide intensive repetitive practice.

Regardless of the type of gait-training strategies used, there is still the unresolved question of who should be encouraged to walk and who has the potential for neurological recovery.[11,67,68] Some argue that all patients should be provided with the opportunity for gait training with treadmills or robotic devices with or without electrical stimulation and therapists to move the paralysed legs, even if the chances of ultimately walking are slim. They argue that

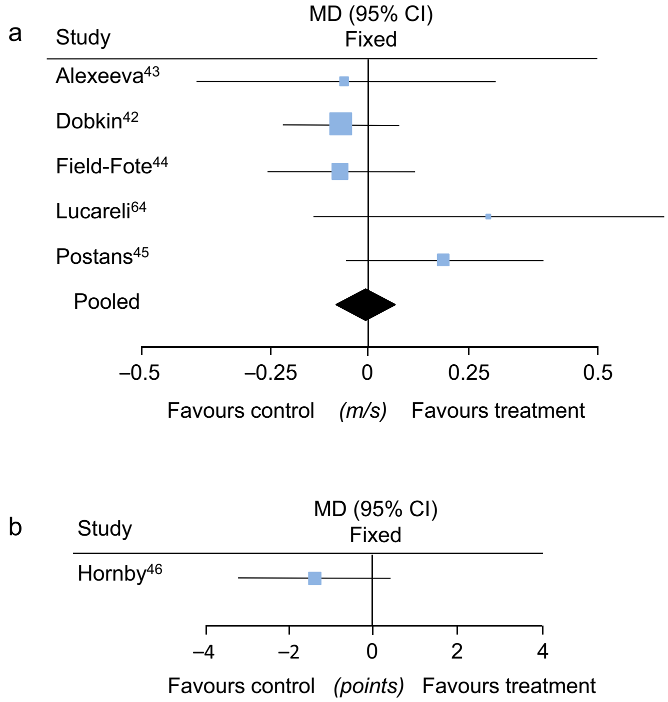


**Figure 4.** Mean difference (MD) of the effect of treadmill gait training with overhead suspension versus control on (a) walking speed and (b) walking index of SCI (WISCI, 21-point scale) in people with SCI.

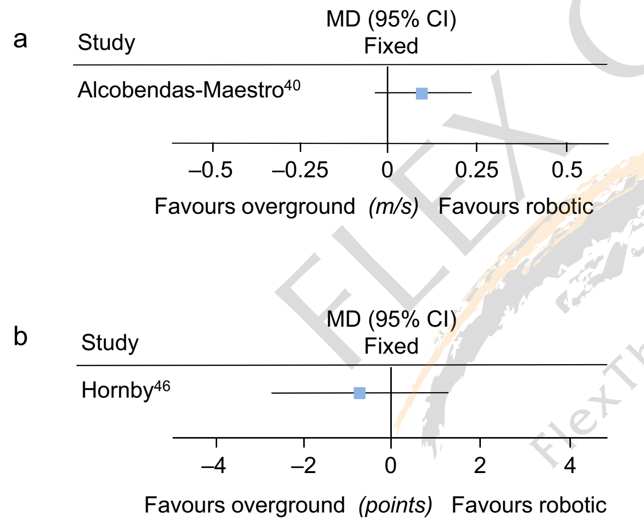


**Figure 5.** Mean difference (MD) of the effect of robotic gait training versus overground training on (a) walking speed and (b) walking index of SCI (WISCI, 21-point scale) in people with SCI.

even if patients do not regain the ability to walk, this type of therapy has other health benefits related to standing and strenuous exercise. Those who are more pragmatic argue that it is not economically feasible for most healthcare systems to provide such costly treatments for everyone without some rationalisation. They also argue that it may even be potentially harmful to encourage all patients to believe that walking is likely when clearly it is not. A sole focus on walking diverts attention away from gaining independence from a seated position; a skill that is currently essential for those who ultimately do not walk.[12,69] There is clearly a need for some balance between the two positions.

## Future directions

The recent focus on neural plasticity and neural recovery following SCI has led to the emergence of a new term, 'activity-based therapy'.[70] Activity-based therapy has been heralded by some as a novel approach to physiotherapy for people with SCI,[71] yet it is surprisingly difficult to get a clear definition of what is meant by this term.[72] A key aspect of activity-based therapy is context-specific and task-specific intensive practice involving many hours of exercise a day, which is not dissimilar to what was advocated by Carr and Shepherd in the 1980s.[73] However, it also includes 'developmental sequencing' exercises, strength training, and treadmill or robotic walking with or without electrical stimulation (see Appendix S1 of the paper by Jones et al[70]). Its proponents argue that it is novel because it focuses on optimising function and neural recovery below the level of the injury. It is argued that this type of therapy is in stark contrast to 'conventional' or 'traditional' therapy, which some believe solely focuses on teaching compensatory strategies with no therapeutic attention directed below the level of injury. Anecdotal evidence suggests that this is not an accurate contrast and that physiotherapists have been directing therapeutic attention below the level of injury long before the emergence of activity-based therapy, albeit primarily in those with at least some signs of motor function. However, regardless of the terminology, there is now evidence from at least one trial indicating that intensive physiotherapy improves gait and strength in people with AIS C and D lesions 3 years after SCI.[70] Some claim that this supports a new type of therapy, while others believe that the therapy provided in this trial is not dissimilar to the therapy that has been provided to people with these types of lesions for many years now and, as such, the trial provides long-overdue evidence to indicate the therapeutic benefits of an intensive and comprehensive physiotherapy program.

Physiotherapy practice may change considerably over the next decade. Exoskeletons are currently available and enable people with lower limb paralysis to walk overground. They are not yet sufficiently versatile to replace the wheelchair, but no doubt this will change as technology improves. Stem cell therapy may also one day open up doors for those with SCI. The future is unknown but there are many reasons for optimism. However, there is still a need to direct research attention to some of the fundamental principles underpinning physiotherapy management of people with SCI. For example, more clinical trials are needed to examine the effectiveness of widely used treatments for the management of different impairments, including weakness, spasticity, pain, osteoporosis, contracture and respiratory compromise. A firm evidence base and understanding of optimal treatments for these key impairments will be essential for future breakthroughs in stem cell therapy, neuroplasticity, robotics or other innovations that the future may bring. However, it will be important that future interventions are not rolled out to become entrenched as standard practice without appropriate scrutiny within clinical trials.[11] The emphasis must remain on high-quality trials to guide evidence-based physiotherapy for people with SCI.

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## Further reading

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# Respiratory Care in Traumatic Spinal Cord Injury


**Abstract**

This article deals with the respiratory management of acute spinal cord injury patients discussing the mechanics of respiration, assessment and management strategies, respiratory care in the acute stage, invasive mechanical ventilation and weaning including survival following spinal cord injury.

The importance of the care in supine position, physiological instability of the injured cord effect of hypoxia and hypovolaemia is also discussed.

A review of relevant literature has been done to try and answer whether early mobilization following acute spinal cord injury is better than active physiological conservative care including slow weaning, reflecting the ethos of treatment for these problems at Oswestry.



**Keywords:** Trauma; Spinal cord injury; Respiratory care; Ventilation; Weaning; Survival; Life expectancy


## Introduction

Spinal injuries without neurological damage have little effects on respiratory function unless associated with injury to the chest wall. Early verticalisation/mobilisation of these patients are safe and likely to improve vital capacity.

Spinal injury with cord damage (SCI) has a profound effect on the mechanics of respiration and on respiratory function particularly in cervical cord injuries. Early mobilisation of patients with high thoracic and cervical cord injuries especially during the stage of spinal shock is likely to cause further reduction in vital capacity added morbidity [1,2]. Respiratory complications are the leading cause of morbidity and death after SCI [3-5]. The degree of respiratory dysfunction depends on pre-existing pulmonary status, the level of SCI, and any associated chest wall or lung injuries as well as on the quality of the management of the physiologically impaired respiratory functions. The more rostral and complete the damage to the spinal cord, the greater the likelihood of major respiratory impairment. The impact of spinal shock on respiratory function following acute spinal cord injury can be severe necessitating a transient need for an artificial airway and mechanical ventilatory assistance. As spinal shock resolves the flaccid paralysis of the chest wall muscles is replaced by spasticity. The chest wall becomes rigid with loss of compliance, while the abdomen is hypercompliant, both contributing to the reduction in tidal volume in the sitting posture resulting in an improvement in respiratory function particularly during inspiration [6]. Additionally, pulmonary function may be impaired in SCI due to the loss of ventilatory muscle function from denervation, concomitant lung injuries such as pneumothorax; haemothorax; or pulmonary contusion and decreased central ventilatory drive that is associated with head injury or the effects of alcohol and drugs.

Around 40% of spinal cord injuries occur in the cervical spine, a trend that is steadily increasing, with respiratory causes being responsible for death in over 20% of individuals [7]. Loss of lung volumes and relative hypoxemia contribute to global hypoxaemia, exacerbating cord ischaemia in the acute period [7-11]. Respiratory compromise results in the loss of muscle strength generation capacity and reduced lung volumes and in particular vital capacity, of up to 70% ineffective cough and secretion clearance abilities [7-11]; reductions in both lung and chest wall compliance and an additional oxygen cost of breathing due to changes in respiratory mechanics, with obstructive sleep apnoea evident in over 50% of acute tetraplegics [12].

While some countries have specialist spinal Centres to manage such catastrophic trauma with a demonstrable improvement in health outcomes attributed to their contribution [13], many individuals are initially admitted to local hospitals where healthcare professionals are less likely to fully appreciate the significant and continued vulnerabilities of such individuals. This article is aimed at providing a basic understanding of the causes and identification of the main principles of the respiratory management strategies required to maintain pulmonary health for cervical SCI patients during the initial and early post trauma phase.

## Respiratory Mechanics

Individuals with spinal cord injury exhibit reduced lung volumes and flow rates as a result of respiratory muscle weakness. These features have been investigated in relation to the combined effects of injury level and posture. Supine values of forced vital capacity and forced expiratory volume in 1s (FEV 1) were repeatedly and consistently shown to be larger in recumbence compared with the seated posture [14-17].

Early mobilisation of patients with spinal neural tissue injury is associated with a reduction of vital capacity and a potential drop of oxygen saturation and/or postural hypotension. Individually or in combination these may further impair cord functions. The tetraplegic and high paraplegic patient's ability to cough is markedly impaired. It is more difficult to get rid of bronchial secretions with assisted coughing against gravity than when patients are in recumbence.

Complete injuries above the mid thoracic region will result in loss of the major respiratory muscle groups for both inspiration and expiration and thus an inability to either fully aerate the lungs or to clear pulmonary secretions, resulting in major vulnerabilities toward pulmonary collapse and infection. Intercostal and abdominal muscle paralysis result in paradoxical chest wall motion i.e., the thorax is pulled in while the hyper compliant abdomen moves out; and loss of diaphragmatic excursion through the zone of apposition [18]. The upright sitting posture results in lower lung volumes than supine lying since the diaphragm loses its ability to generate the same force of contraction [14-19].

Thus while somewhat counterintuitive to the respiratory clinician, the supine position should be adopted in times of respiratory compromise and throughout the process of weaning from mechanical ventilation in complete cord lesions. The use of abdominal binders applied over the lower ribs and abdomen, is common practise in the specialist Centres for use in the upright position [20], improving the VC by as much as 0.32 litres [21]. This application may in borderline cases, offset the need for respiratory support.

## Assessment and Management Strategies

The clinical assessment of pulmonary function in acute spinal cord injury begins with a careful history regarding respiratory symptoms and a review of underlying cardiopulmonary co-morbidity such as chronic obstructive pulmonary disease or heart failure. Evaluation also includes respiratory rate, chest wall expansion, abdominal wall movement, and force of cough, chest, limbs and other associated injuries according to a detailed secondary survey. Arterial blood gas analysis and pulse oximetry are especially useful because the bedside diagnosis of carbon dioxide ($CO_2$) retention or hypoxia may be difficult.

Atelectasis and pneumonia pose significant morbidity and are reported in 40-70% of cases. Respiratory assessment should be vigilant, simple and repeated frequently at the bedside to warn of impending or frank respiratory failure. Aggressive respiratory management has been advocated for the prevention and treatment of pulmonary complications and has been associated with improved outcomes [3,22,23].

As a minimum, the Vital Capacity (VC), Respiratory Rate (RR) and oxygen saturation ($SaO_2$) should all be monitored regularly, and their trends considered, preferably with arterial blood gases (ABG's) performed at frequent intervals during the first few weeks post injury. The initial reduction of VC in the acute phase will increase steadily within the first five weeks post injury [8]. While a reduction in VC to 10 ml/kg body weight is accepted, further reductions due to loss of compliance or increased resistance (e.g. atelectasis and/or infection), will cause rapid deterioration while a peak cough flow rate (which reduces with lower VCs) of at least 1601/s is essential to shear mucus along the airway walls, for airway clearance [24]. The provision of assisted cough to increase the mucus clearance ability [25], either manually or mechanically is vital in reducing the risk of pulmonary complications and subsequent respiratory failure.

A VC < 700 ccs may be inadequate to sustain spontaneous breathing and is a major indicator to provide ventilatory support. Prompt support with Non Invasive Ventilation (NIV) may enable the avoidance of invasive tracheal intubation in acute SCI [26]. However, halo fixation may pose particular difficulties with mask fitting for NIV therapy while other risks associated with NIV in a non-specialised spinal Centre include the ASCI patient being susceptible to profound and rapid desaturation, silent fall into respiratory failure, paralytic ileus, and risk of air swallowing with an increased risk of acute vomiting and aspiration. The loss of arm and hand function must not be forgotten when selecting the NIV interface.

Neurological deficits may be asymmetrical so the all-important diaphragm should be considered as two separate halves. Paralysis of a single hemi-diaphragm in a complete cervical spine injury, which may go unnoticed by the untrained eye, may require longer term or at least part-time respiratory support, since all intercostal and abdominal muscle activity will be lost. (There has been identified more recently a crossed phrenic nerve pathway thought able to support the contralateral diaphragm, though the clinical implications of this have not yet been fully explored [27]). Where diaphragm function is uncertain, more detailed assessment in the form of fluoroscopic screening [28], M mode ultrasound [29] and surface EMG are all useful assessment tools.

Aspiration poses a significant risk in the tetraplegic patient. Kirshblum et al., [30] studied 187 acute SCIs. Forty two patients had signs of aspiration with video fluoroscopic confirmation in 31 of these. Kirshblum's independent predictors of dysphagia by VFSS were tracheostomy tube at the time of admission, recent cervical spine surgery particularly with an anterior approach, and age. Clinically, aspiration often goes unnoticed but may present as repeated respiratory infections or repeated/persistent lobar collapses. Assessment of swallowing with speech and language therapist input is vital, as salivary and/or food aspiration can have a major detrimental impact upon respiratory health and complicate the ongoing management. Medications should be reviewed due to the effects of some, on muscle fibres e.g. corticosteroids and lipid lowering agents. The profound psychological impact of denying oral intake in the medium and/or longer term, in a high SCI individual should not be overlooked.

## Respiratory Care in the Acute Stage

An Oswestry experience of respiratory management in self-ventilating tetraplegia patients.

The Midland Centre for Spinal Injuries is one of twelve tertiary specialised spinal injury Centres within the United Kingdom. This 44 bedded centre is dedicated to the specialist care for patients with spinal injury and provides holistic acute management, comprehensive rehabilitation and lifelong care for those living with spinal cord injuries. The Centre caters to a wide geographic area including the West Midlands, north and mid-Wales and the south of the North West region (Cheshire) – a population of the order of approximately 10 million people. Approximately 120 'new' SCI patients are admitted each year.

As a preventative measure, the Centre has an intensive management programme of respiratory care. This includes three hourly high side turns on a mechanical bed with turning system or manual side turns; regular deep breathing exercises; use of incentive spirometry to optimise lung capacity, assisted coughing for secretion clearance; use of non-invasive biphasic positive airway pressure (BIPAP) as a routine prophylactic treatment for improving lung capacity and preventing atelectasis rather than as a mechanism for assisted ventilation. A Cough Assist machine is also used in selected patients. In later stages inspiratory training is used with the Train Air, which is a computer programme linked to an inspiratory mouthpiece. High tetraplegic patients use this as part of their gymnasium routine like a paraplegic would use the weights machines. The biggest result is increased voice projection. Close monitoring of respiratory function is also carried out relying on respiratory rate, pulse oximetry, regular use of micro spirometer to record vital capacity, monitoring peak flow where relevant and arterial blood gas analysis. Care is also taken to ensure adequate hydration and all oxygen delivered is humidified.

Almost all patients with a SCI are offered an active physiological conservative management for their spinal cord injury with a period of recumbence for about 6 weeks.

A previous internal audit in 2007 had looked into the respiratory complications in tetraplegic patients before and after transfer between 2003 and 2004 to this Centre. This had showed that such preventative measures were successful but identified certain areas to improve.

The re-audit was a retrospective study looking into the respiratory

| Frankel grade | High Cervical (C1 – C4) (n=50) | Lower Cervical (C5-T1) (n=55) |
|---|---|---|
| A | 6 | 18 |
| B | 16 | 16 |
| C | 62 | 37 |
| D | 16 | 29 |

**Table 1:** Showing the neurological level and density by Frankel grade.

complications amongst all acute tetraplegic patients admitted over three year period between 2007 and 2009. Patient and injury demographics, respiratory complications (i.e., pneumonic consolidation, collapse or atelectasis, pulmonary embolism, effusion) before and after admission to the Centre, method of management of the spinal column injury, the respiratory management and changes in vital capacity were reviewed. 105 patients with a tetraplegia Frankel Grade A to D was included. 73 were males and 32 were females. The mean age was 51 years (at the previous audit this was 44 years) with 31% over 65 years of age (Table 1).

Mean delay in transfer from the referring hospitals to the Centre was 24 days (although almost 25% were admitted within one week of injury and approximately 48% within two weeks). 28% (29/105) had a respiratory complication prior to transfer to the Centre, majority of which was pneumonia /consolidation (90%). 48% of those with a respiratory complication (14/29) had required a period of invasive ventilation prior to transfer.

All patients had undergone the same preventative management programme of respiratory care. Of the 20 patients who did develop a respiratory complication after transfer to the Centre, eleven had already had respiratory complication prior to their transfer. Only 9 out of 105 patients had a 'new' respiratory problem (5 infections, 4 of whom required antibiotic therapy; whilst pulmonary embolus, postoperative period of ventilation following a gastro-intestinal surgery, pulmonary effusion and a pneumothorax accounted for the remaining cases). This study had shown that respiratory complications are potentially preventable in self-ventilating tetraplegic patients with a comprehensive management programme.

## Invasive Mechanical Ventilation, Weaning and Life Expectency

The likelihood of tracheostomy requirement for ventilation post-surgical fixation [31] is increasingly common outside the specialist Centres. When diaphragm function is lost, invasive mechanical ventilatory support is essential, though recovery has been seen to occur as late as 24 months post injury [32]. Regardless of the timing, the method of ventilation for SCI patients requires larger tidal volumes [33] (at least 10-15 mls/kg), to ensure effective aeration of the lung bases and avoidance of atelectasis and infection. This is well tolerated by SCI patients, with no known evidence to demonstrate pulmonary damage in the absence of acute lung injury. The effect of large volume ventilation is that of respiratory alkalosis, with no long term detrimental effect from this [34]. Electrolyte monitoring in the acute stabilisation phase is required.

The discontinuation of mechanical ventilatory support is likely to take some weeks to achieve. Consistent factors underpinning successful weaning after spinal cord damage have been attributed to accurate neurological assessment; prevention of pulmonary atelectasis by regular and frequent respiratory physiotherapy; ventilator free breathing (VFB) graduated according to VC; rest periods with controlled ventilation; cuff deflation allowing translaryngeal air flow, and regular tracheostomy tube changes [35]. It may be useful to highlight the significant incidence of sleep apnoea (both central and obstructive in nature) in tetraplegia immediately post injury [36,37] which increases over time [38], as this is likely to complicate the respiratory picture and even delay weaning if unrecognised.

Watt et al. compared the long-term survival of 262 patients who were having mechanical ventilation on discharge from a single Spinal Injury Centre with the cohort who had been weaned from mechanical ventilatory support prior to discharge, and examined the causes of death and contributory factors. Mean survival was better amongst weaned compared to ventilated patients [39]. The survival from initial ventilation was poor for the older age group, and for the middle age group who remained on ventilation. Patients with any comorbidity had substantially poorer survival. Groups defined by the AIS scale did not differ strongly, and survival did not differ significantly by neurological level. Pre-existing comorbidities increased the mortality rate by 3.3 [40].

## Conclusions

In summary acute SCI may be one of the most devastating acute conditions with respiratory dysfunction providing a major cause of mortality and morbidity; the level and completeness of injury being major determinants of the extent of respiratory dysfunction. Other concomitant injuries and co-morbidities not incorporated here will have further detrimental impacts. Spinal cord injuries are often admitted to a local hospital or trauma centre, so early referral and consultation to a specialist centre when available, where improved health outcomes are achieved, is of paramount importance. Good respiratory health is more likely by ensuring full aeration of the lungs, with proactive chest clearance regimens and monitoring in the acute stage (though vulnerabilities are lifelong). This will also reduce the likelihood of secondary hypoxic cord damage. The minimum basic strategies with complete lesions should include the adoption of large volume ventilation while ventilator-dependant; the supine lying position for maximal spontaneous tidal volume exchange and throughout the weaning process; the monitoring of the vital capacity and use of an abdominal binder when upright. Advice, guidance and support from the local tertiary spinal centre should be sought as soon as cord damage is suspected/realised, to ensure the best management strategies are utilised from the outset for all systems and aspects of care.

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# A behavioural intervention increases physical activity in people with subacute spinal cord injury: a randomised trial


KEY WORDS

Spinal cord injury
Motor activity
Behaviour modification
Physical activity
Physical therapy



ABSTRACT

**Questions:** For people with subacute spinal cord injury, does rehabilitation that is reinforced with the addition of a behavioural intervention to promote physical activity lead to a more active lifestyle than rehabilitation alone? **Design:** Randomised, controlled trial with concealed allocation, intention-to-treat analysis, and blinded assessors. **Participants:** Forty-five adults with subacute spinal cord injury who were undergoing inpatient rehabilitation and were dependent on a manual wheelchair. The spinal cord injuries were characterised as: tetraplegia 33%; motor complete 62%; mean time since injury 150 days (SD 74). **Intervention:** All participants received regular rehabilitation, including handcycle training. Only the experimental group received a behavioural intervention promoting an active lifestyle after discharge. This intervention involved 13 individual sessions delivered by a coach who was trained in motivational interviewing; it began 2 months before and ended 6 months after discharge from inpatient rehabilitation. **Outcome measures:** The primary outcome was physical activity, which was objectively measured with an accelerometer-based activity monitor 2 months before discharge, at discharge, and 6 and 12 months after discharge from inpatient rehabilitation. The accelerometry data were analysed as total wheeled physical activity, sedentary time and motility. Self-reported physical activity was a secondary outcome. **Results:** The behavioural intervention significantly increased wheeled physical activity (overall between-group difference from generalised estimating equation 21 minutes per day, 95% CI 8 to 35). This difference was evident 6 months after discharge (28 minutes per day, 95% CI 8 to 48) and maintained at 12 months after discharge (25 minutes per day, 95% CI 1 to 50). No significant intervention effect was found for sedentary time or motility. Self-reported physical activity also significantly improved. **Conclusion:** The behavioural intervention was effective in eliciting a behavioural change toward a more active lifestyle among people with subacute spinal cord injury.




## Introduction

People with spinal cord injury (SCI) receiving inpatient rehabilitation are physically active during therapy sessions. However, after discharge from inpatient rehabilitation, daily physical activity levels are known to decline to a level that is severely low compared with the general population and also low compared with people with other chronic diseases.[1,2] In addition to maintaining sufficient physical activity, interposing of breaks in sedentary time is another independent aspect of physical behaviour that is thought to be important for optimal health.[3,4] For people with SCI, increasing the amount of physical activity is known to: reduce the risk of cardiovascular disease; prevent or reduce secondary health problems, such as pressure areas; and improve physical fitness and quality of life.[5,6] Thus, it is important to prevent a decline in physical activity levels and promote an active lifestyle in the home situation of people with subacute SCI.

Physical capacity can be regarded as a prerequisite for an active lifestyle. Higher physical capacity may allow individuals to perform activities in daily life more proficiently, faster, with less difficulty and for longer periods.[7] Nevertheless, people with SCI often have poor physical capacity.[8] In recent years, it has become increasingly recommended that the highest possible level of physical capacity is attained during inpatient rehabilitation.[5,9] However, higher physical capacity may not automatically lead to a more active lifestyle; a behavioural change may also be needed.[10]

Behavioural interventions are thought to be necessary to achieve a change in behaviour. Previous studies of people with SCI have tended to show positive effects of behavioural interventions on physical activity.[11–16] However, all of those studies were performed on people with SCI in the chronic phase. Furthermore, only one study[13] used objective measures of physical activity; the others used self-reported measures, which might have permitted bias.[17] Moreover, only two of six studies[14,15] reported on the long-term effects, which was a limitation because the new behaviour will only be clinically relevant if it is maintained after the intervention.

In the present study, it was hypothesised that regular rehabilitation including a physical exercise intervention reinforced with the addition of a behavioural intervention to promote physical activity would lead to a more active lifestyle than regular rehabilitation including a physical exercise intervention. Therefore, the primary objective of the study was to determine the effect of adding the behavioural intervention on physical activity. A secondary objective was to determine the effects on physical capacity, health, participation and quality of life; these outcomes will be reported in a separate publication.

Therefore, the research question for this randomised, controlled trial was:

> For people with subacute SCI, does rehabilitation that is reinforced with the addition of a behavioural intervention to promote physical activity lead to a more active lifestyle than rehabilitation alone?

## Method

### *Design*

This study, named Act-Active, was a single-blind, multicentre, randomised, controlled trial with blinding of the research assistants who performed the measurements. The first author randomised the participants to an intervention group or a control group by a concealed allocation procedure. Randomisation was stratified by level of injury (tetraplegia versus paraplegia) and completeness of injury (motor complete versus motor incomplete). A lesion between C5 and T1 was defined as tetraplegia, and a lesion below T1 as paraplegia. A motor complete lesion was defined as AIS grade A or B, a motor incomplete lesion as AIS grade C or D.[18] Block randomisation was by a computer-generated random number list prepared by an investigator with no clinical involvement in the trial. Random group allocation (1:1) was performed for each rehabilitation centre and within each stratum.

### *Participants, therapists and centres*

Research assistants at rehabilitation centres with specialised SCI units enrolled participants during inpatient rehabilitation. Inclusion criteria were: diagnosed with SCI, initial inpatient rehabilitation, dependent on a manual wheelchair, able to handcycle, and aged between 18 and 65 years old. Exclusion criteria were: insufficient comprehension of the Dutch language to understand the purpose of the study and its testing methods, and progressive disease or a psychiatric condition that could interfere with participation. The usual staff at the specialised rehabilitation centres administered the rehabilitation. The behavioural intervention was delivered by a physiotherapist or occupational therapist trained in motivational interviewing. The four Dutch rehabilitation centres that were involved were: Rijndam Rehabilitation Institute in Rotterdam, Adelante in Hoensbroek, Heliomare in Wijk aan Zee, and Hoogstraat in Utrecht.

### *Intervention*

All participants in both groups received usual care, which included a handcycle training program and advice on physical activity after discharge. The structured handcycle training program was performed during the last 8 weeks of inpatient rehabilitation. This handcycle training was scheduled three times per week and consisted of an interval training protocol on an add-on handcycle. Details of the handcycle training and results on physical capacity have been described elsewhere.[19] The advice about physical activity after discharge was unstructured and focused mainly on sports and not on daily activities. After inpatient rehabilitation, all participants continued rehabilitation as outpatients.

Participants in the experimental group received an additional behavioural intervention. This intervention aimed to increase the amount of everyday physical activity after discharge from inpatient rehabilitation. Thirteen individual face-to-face sessions with a coach were planned, each session having a maximum duration of 1 hour. For practical reasons, some sessions after discharge were conducted by telephone. Two sessions were scheduled per month beginning 2 months before discharge and ending 3 months after discharge; thereafter, in the following 3 months there was one session per month. Each physiotherapist or occupational therapist who acted as coach for the behavioural intervention was trained in motivational interviewing, as based on the transtheoretical model. Motivational interviewing has been shown to be an effective method for altering behaviours.[20]

Each session began with the participant proposing the topics of conversation for that session. The behavioural intervention had four main components. The first component was feedback on daily wheelchair activity using bicycle odometers. A bicycle odometer was attached to the wheelchair and registered the distance travelled per day. The participant was instructed to keep track and to set goals toward increasing the travelled distance. The second component was formulation of action plans on how and when to be physically active and formulation of coping strategies for dealing with barriers that could hinder the actual performance of an action plan. The next component was a home visit by the coach in the first month after discharge, during which the coach helped to optimise the home and the environment of the participant for an active lifestyle. The last component was the provision of additional information at the request of the participant on relevant topics related to physical activity, such as possible health benefits.

### *Outcome measures*

Measurements were performed at four scheduled assessment points: 2 months before discharge from inpatient rehabilitation, which was before the start of the interventions (baseline); 1 or 2 weeks before discharge from inpatient rehabilitation (discharge); 6 months after discharge from inpatient rehabilitation, which was within 1 month after completion of the behavioural intervention; and 1 year after discharge from inpatient rehabilitation. Each participant's start in the study was determined based on the planned discharge date, as estimated by the rehabilitation physician.

*Objective measurement of physical activity*

Physical activity was measured objectively with an ambulatory monitoring system[a] (Figure 1), with body-fixed three-axis

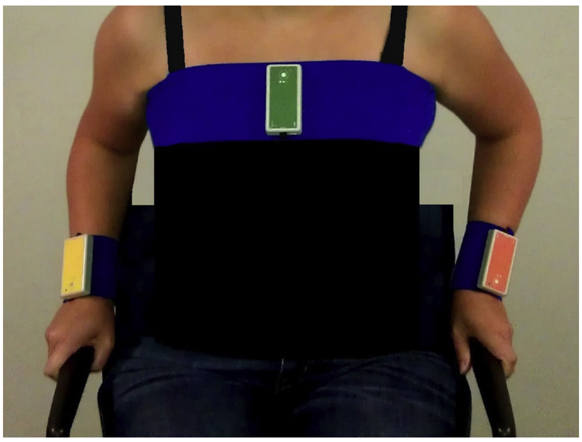

**Figure 1.** Activity monitor[a] used in the study.

accelerometers.[b] This monitoring system validly quantifies mobility-associated activities and postures, and detects inter-group differences in physical activity, including in people with SCI.[21,22] The system consists of three recorders that are wirelessly connected and synchronised every 10 seconds. One recorder was attached to each wrist and a third recorder to the sternum, using specially developed belts. At each scheduled assessment point, the recorders were worn continuously for 96 hours on four consecutive weekdays during all activities, except swimming, bathing and sleeping. The minimal acceptable duration of a measurement was 24 hours,[23] and outcomes were averaged over all available 24-hour periods for each scheduled assessment point. Participants were asked to note in a diary the time and duration of swimming, so that these periods could be corrected manually. To avoid measurement bias, participants were advised not to alter their usual activities and therapy on the days that the accelerometers were worn. Accelerometer signals of each recorder were sampled and stored on a digital memory card. Measurements were uploaded to a computer for kinematic analysis using commercial software.[c] Details of the configuration and analysis have been described elsewhere.[22,24]

The accelerometry data were analysed to generate several outcomes. The first outcome was total duration of wheeled physical activity, expressed in minutes per 24-hour period. Wheeled physical activity included both wheelchair propulsion and handcycling. In addition, the total duration of wheelchair propulsion and handcycling were also determined separately, again expressed in minutes per 24-hour period.

Further detailed information on wheelchair propulsion was gained by analysing the number of total continuous wheelchair propulsion bouts lasting longer than 5 seconds. These wheelchair propulsion bouts were analysed in pre-defined categories of bout duration (5 to 10 seconds, 10 to 60 seconds, and 1 to 10 minutes).

Sedentary daytime was analysed as the total duration of sedentary daytime bouts longer than 30 minutes. Sedentary daytime was defined as sitting and lying during the day without interruption by physical activity for a minimum of 5 seconds, expressed in minutes per 24-hour period. Lastly, mean motility per 24-hour period was analysed. Motility is based on the variability of the accelerometer signal of the trunk and arm recorders and is a measure of intensity and duration of all movement, expressed in gravitational force (g).[22]

*Self-reported physical activity level*

Self-reported physical activity levels were measured with the Dutch version of the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD), which is a 13-item, 7-day recall questionnaire developed for people with a physical disability.[25] This tool consists of questions regarding leisure time, household-related and work-related physical activity. The total PASIPD score was calculated by multiplying the average hours per day for each item by a given metabolic equivalent (MET) value associated with the intensity of the activity. Because the questionnaire is not suitable for people in inpatient rehabilitation, self-reported physical activity was only measured at 6 and 12 months after discharge.

### Data analysis

Forty-two participants were required to detect a 30-minute difference per 24-hour period in objectively measured, wheeled physical activity between the experimental group and the control group, with an anticipated standard deviation of 35 minutes,[26] power of 0.8, and an alpha of 0.05. The study aimed to recruit 60 participants to allow for dropouts. The power analysis was based on a previous study, from the same department, on the physical activity level of people with subacute SCI.[1] The power analysis did not consider repeated measurements or missing values. Independent *t*-tests and Chi-square tests were used to test for differences in personal characteristics, lesion characteristics and baseline physical activity between the dropouts of both groups.

To determine the effects of adding the behavioural intervention to usual rehabilitation, Generalised Estimating Equation (GEE) analyses with exchangeable correlation structures were performed. First, overall models for each outcome variable were made, including group allocation and baseline values of the particular outcome variable. Then, we assessed the between-group differences for the three follow-up measurements (before discharge, 6 and 12 months after discharge) by adding time and a group-by-time interaction variable to the overall models. The between-group difference, *p* and confidence intervals for the crude models were presented, and the models were adjusted for rehabilitation centre, gender and age. The between-group difference of the overall model represents the between-group difference estimated over all measurements using the GEE, and the between-group difference at the specified measurement time represents the mean between-group difference at that time. The control group was the reference group for all analyses. In the case of missing values at baseline, data of the particular participant from the second measurement were imputed to the baseline measurement of that participant. No baseline measurements were available for self-reported physical activity and, therefore, baseline corrections were performed using the baseline data of objectively measured physical activity.

## Results

### Flow of participants, therapists and centres through the study

Between January 2011 and August 2013, 45 people with subacute SCI were enrolled in the study (Figure 2). Three participants in the experimental group and three in the control group dropped out before the second measurement and therefore could not be included in the analysis. Dropouts in the experimental group (n = 12) and in the control group (n = 11) did not differ substantially in terms of personal or lesion characteristics and physical activity at baseline. Baseline personal and lesion characteristics of the remaining 39 participants are presented in Table 1. Participants completing the behavioural intervention attended on average 73% of sessions.

For logistic and technical reasons, the intended measurement duration with the activity monitor was not always met. Average measurement duration with the activity monitor was 65 hours (SD 26, range across all measurement occasions 58 to 72 hours) out of the intended 96 hours. A total of 112 activity monitor measurements were available (35 at baseline, 30 before discharge, 27 at 6 months after discharge, and 20 at 12 months after discharge). Two measurements at baseline were missing due to logistic problems, five measurements at discharge were missing due to unexpected early discharge from inpatient rehabilitation, two discharge measurements and one measurement 6 months after discharge were unavailable due to technical problems and 10 measurements (two at baseline, three before discharge, three at 6 months after discharge, and two at 12 months after discharge) were unavailable because the participant did not wear the activity monitor for at least 24 hours.

We planned to perform an intention-to-treat analysis, and therefore we included all available data in the analysis. Unfortunately, we were not able to obtain physical activity data in participants who dropped out of the study for different reasons: some refused to perform the activity monitor measurement; some measurement was not possible due to medical complications; and in the persons that dropped out because they were no longer dependent on a manual wheelchair, measuring wheeled physical activity is useless.

### Intervention effects

Figure 3 presents the observed data of objectively measured, wheeled physical activity. Table 2 presents the observed data for the remaining outcome measures. The modelled data are

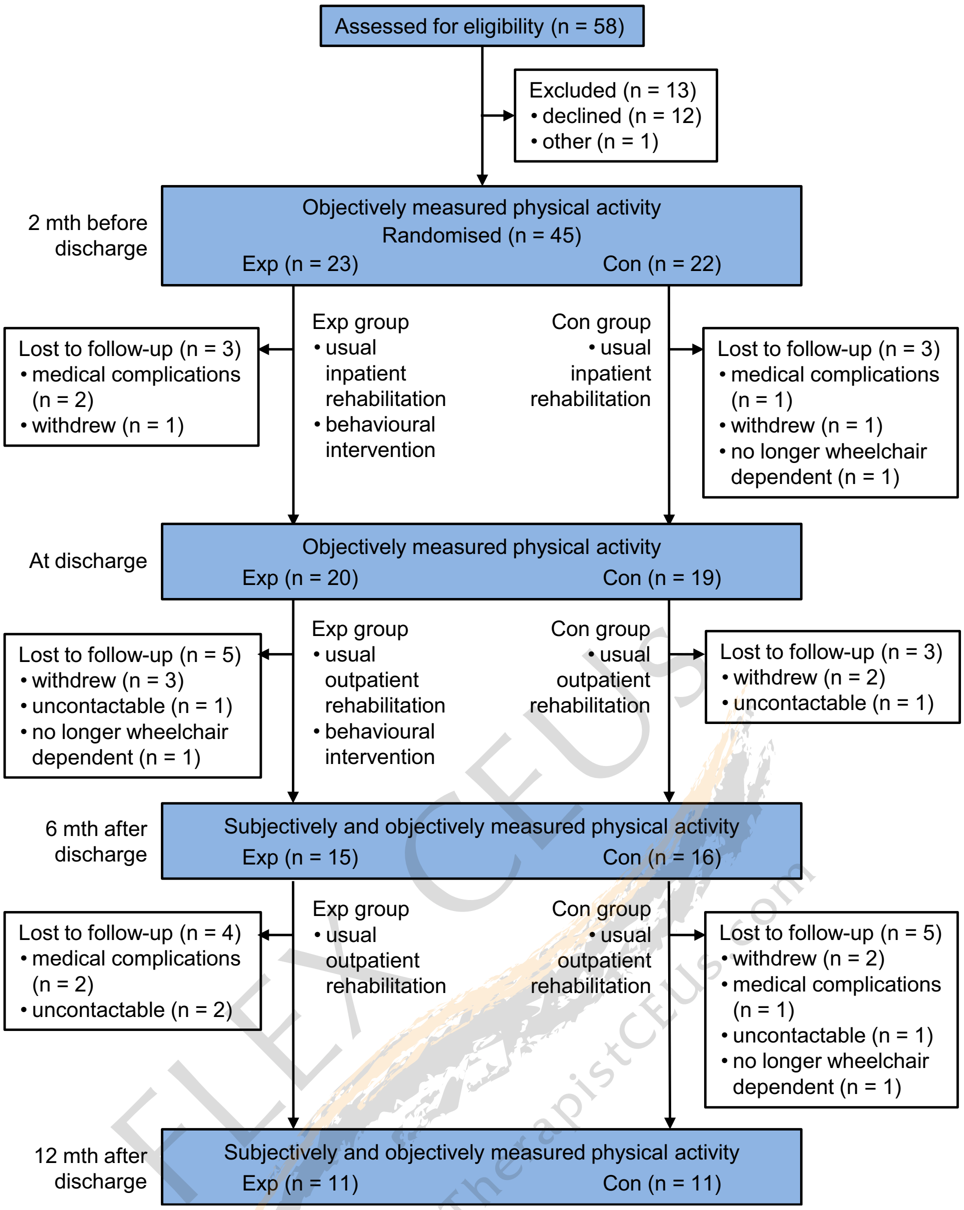


**Figure 2.** Flow of participants through the study.



presented in Table 3. (Individual participant data are presented in Table 4; see eAddenda for Table 4). Overall intervention effects were found for wheeled physical activity, wheelchair propulsion, handcycling and self-reported physical activity. At 6 months after discharge, the behavioural intervention increased wheeled physical activity by a mean of 28 minutes per day (95% CI 8 to 48). At 12 months after discharge, the behavioural intervention increased wheeled physical activity by a mean of 25 minutes per day (95% CI 1 to 50). For wheelchair propulsion, the intervention effect was largest at 6 months after discharge (mean between-group difference 20 minutes per day, 95% CI 5 to 34). For handcycling, the intervention effect was largest at 12 months after discharge (mean between-group difference 16 minutes per day, 95% CI –1 to

**Table 1**
Characteristics of participants at baseline.

| Characteristics | Exp (n = 20) | Con (n = 19) |
|---|---|---|
| Personal | | |
| age *(yr)*, mean (SD) | 44 (15) | 44 (15) |
| gender, n (%) male | 17 (85) | 16 (84) |
| Lesion | | |
| lesion level, n (%) tetraplegia | 7 (35) | 6 (32) |
| completeness, n (%) motor complete | 13 (65) | 11 (58) |
| time since injury *(d)*, mean (SD) | 139 (67) | 161 (81) |
| time since admission *(d)*, mean (SD) | 104 (64) | 108 (60) |
| cause, n (%) traumatic | 14 (70) | 12 (63) |

Con, control group; Exp, experimental group.

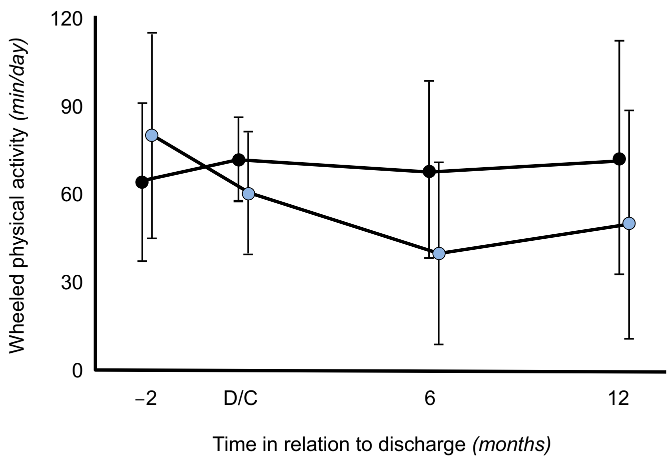


**Figure 3.** Observed data for objectively measured, wheeled physical activity for the experimental (black) and control (blue) groups. D/C = discharge.

**Table 2**
Mean (SD) for outcomes for each group at each assessment time.

| Outcome | Groups | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Baseline | | Discharge | | Month 6 | | Month 12 | |
| | Exp | Con | Exp | Con | Exp | Con | Exp | Con |
| | (n = 18) | (n = 17) | (n = 16) | (n = 14) | (n = 13) | (n = 14) | (n = 10) | (n = 10) |
| Wheeled physical activity *(min/d)* | 65 (27) | 80 (35) | 72 (14) | 61 (21) | 68 (30) | 40 (31) | 73 (40) | 50 (39) |
| Wheelchair propulsion *(min/d)* | | | | | | | | |
| total | 55 (25) | 68 (34) | 59 (16) | 46 (16) | 51 (28) | 32 (21) | 46 (25) | 38 (28) |
| in bouts of 5 to 10 s | 8 (3) | 10 (5) | 8 (3) | 7 (2) | 12 (7) | 7 (5) | 10 (4) | 10 (5) |
| in bouts of 10 to 60 s | 32 (14) | 41 (19) | 35 (10) | 29 (11) | 32 (19) | 20 (13) | 29 (17) | 23 (19) |
| in bouts of 1 to 10 min | 14 (11) | 17 (13) | 16 (10) | 10 (6) | 6 (5) | 4 (4) | 7 (6) | 5 (5) |
| Handcycling *(min/d)* | 10 (10) | 12 (14) | 13 (13) | 14 (8) | 17 (20) | 8 (17) | 26 (30) | 12 (15) |
| Sedentary daytime *(min/d)* | 147 (100) | 119 (104) | 128 (94) | 126 (102) | 212 (133) | 242 (187) | 254 (174) | 244 (180) |
| Motility *(g)* | 16 (5) | 17 (4) | 16 (4) | 16 (4) | 15 (5) | 13 (5) | 17 (5) | 14 (6) |
| Self-reported physical activity [a] *(MET*hr/d)* | – | – | – | – | 32 (34) | 10 (8) | 26 (11) | 11 (12) |

Exp = experimental group, Con = control group.
[a] Physical Activity Scale for Individuals with Physical Disabilities (PASIPD).

**Table 3**
Crude and adjusted mean (95% CI) difference between groups from GEE models.

| Outcome | Crude difference between groups | | | | Adjusted difference between groups[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Overall | Discharge minus baseline | Month 6 minus baseline | Month 12 minus baseline | Overall | Discharge minus baseline | Month 6 minus baseline | Month 12 minus baseline |
| | Exp minus Con | Exp minus Con | Exp minus Con | Exp minus Con | Exp minus Con | Exp minus Con | Exp minus Con | Exp minus Con |
| | | (n = 28) | (n = 27) | (n = 20) | | (n = 28) | (n = 27) | (n = 20) |
| Wheeled physical activity *(min/d)* | 22 (6 to 37) | 10 (−8 to 21) | 29 (7 to 50) | 26 (−2 to 54) | 21 (8 to 35) | 10 (0 to 20) | 28 (8 to 48) | 25 (1 to 50) |
| Wheelchair propulsion *(min/d)* | | | | | | | | |
| total | 13 (4 to 23) | 9 (0 to 19) | 20 (5 to 35) | 8 (−10 to 25) | 13 (4 to 23) | 9 (1 to 18) | 20 (5 to 34) | 8 (−9 to 24) |
| in bouts of 5 to 10 s | 2 (1 to 4) | 1 (−0 to 3) | 5 (1 to 8) | 0 (−3 to 3) | 2 (1 to 4) | 2 (−0 to 3) | 5 (1 to 8) | 0 (−3 to 3) |
| in bouts of 10 to 60 s | 8 (2 to 14) | 5 (−1 to 10) | 13 (4 to 23) | 4 (−7 to 16) | 8 (2 to 14) | 5 (−1 to 11) | 14 (5 to 21) | 4 (−7 to 15) |
| in bouts of 1 to 10 min | 3 (0 to 5) | 3 (−2 to 8) | 3 (−1 to 7) | 2 (−2 to 7) | 2 (−0 to 5) | 2 (−2 to 7) | 2 (−1 to 5) | 2 (−3 to 6) |
| Handcycling *(min/d)* | 8 (−1 to 17) | −1 (−8 to 7) | 10 (−4 to 23) | 17 (−3 to 37) | 8 (1 to 15) | 1 (−7 to 10) | 9 (−4 to 22) | 16 (−1 to 34) |
| Sedentary daytime *(min/d)* | −40 (−110 to 32) | −21 (−69 to 25) | −56 (−152 to 25) | −20 (−127 to 86) | −34 (−97 to 29) | −14 (−69 to 40) | −50 (−134 to 33) | −21 (−119 to 77) |
| Motility *(g)* | 1.74 (−0.42 to 3.90) | 0.32 (−1.43 to 2.07) | 2.05 (−1.43 to 5.54) | 3.17 (−0.50 to 6.85) | 1.24 (−0.25 to 2.73) | 0.06 (−2.15 to 2.27) | 1.75 (−1.01 to 4.52) | 1.98 (−0.65 to 4.61) |
| Self-reported physical activity [b] *(MET*hr/d)* | 20 (7 to 33) | – | 22 (4 to 39) | 17 (6 to 28) | 20 (8 to 33) | – | 21 (5 to 38) | 19 (7 to 30) |

Exp = experimental group, Con = control group.
[a] Adjusted for rehabilitation centre, gender and age.
[b] Physical Activity Scale for Individuals with Physical Disabilities (PASIPD).



34), although this was not statistically significant. Analyses of wheelchair propulsion bouts showed that the largest overall intervention effect was for bouts of 10 to 60 seconds (between-group difference 8 minutes, 95% CI 2 to 14).

In order to investigate the category of activity intensity that most contributed to the overall effect of the behavioural intervention on physical activity, the individual participants' data were plotted. It was observed that the behavioural intervention had the effect of preventing the participants from having a very inactive lifestyle. Therefore, a post hoc test was conducted based on the proportion of participants who had a physical activity level < 30 minutes per day. In the experimental group, 6 months after discharge, none of the participants had a physical activity level < 30 minutes per day, whereas in the control group there were seven participants (50%) with an activity level < 30 minutes per day. One year after discharge, there was one person (10%) in the experimental group and four (40%) people in the control group with activity levels < 30 minutes per day (data not shown).

## Discussion

It is believed that this was the first study performed to assess the added value of a behavioural intervention on objectively measured physical activity in people with subacute SCI. The addition of a behavioural intervention was successful in preventing the decline in physical activity level after discharge[1] and resulted in 50% more wheeled physical activity. Moreover, the more active lifestyle was maintained for 1 year after discharge from inpatient rehabilitation.

Although the behavioural intervention resulted in more wheeled physical activity, the mean activity level in the experimental group was still only 1 hour and 13 minutes per 24 hours. Compared with the general population, the mean physical activity level of the experimental group was only 50% of that of the general population.[2] Possibly, physical strain (ie, the load of daily physical activities relative to physical capacity) is higher in people with SCI. Furthermore, for this group, daily self-care is already time-consuming and a strenuous everyday activity,[27] which leaves less time and energy for dynamic activities. Unfortunately, physical strain was not assessed in the present study. Future research on behavioural interventions should study physical strain and its relationship with physical fitness and health in people with subacute SCI.

The behavioural intervention had little focus on sedentary time during the day. This might explain the relatively small between-group differences on this outcome measure. Focusing more on breaking up long periods of sedentary daytime might optimise the intervention. However, breaking up sedentary time in people who are wheelchair dependent is difficult because sitting less is not possible. It is unknown for this group what type, intensity and duration of activity are necessary to break up sedentary time for health benefits.[4] Future studies should focus more on sedentary time in relationship to health benefits in people who are wheelchair dependent.

Of the previous studies performed on people with SCI in the chronic phase, only one study used an objective measure of physical activity and found no significant effect of the intervention.[13] When comparing our objective and self-reported between-group effects, the effect on the self-reported measure confirmed our objective results, but was relatively much larger (100% versus 50% of the mean). This confirms previous findings that self-reported measures overestimate changes in physical activity level.[17] Therefore, especially in intervention studies where self-reported outcomes could be biased by socially desirable answers, care should be taken not to draw strong conclusions from questionnaires on physical activity.

The main limitations of the present study were the small sample size, missing values and dropouts. However, despite these limitations, significant between-group differences were found in the primary outcome measure. Based on inclusion rates in a previous cohort study, the present study was expected to be able to enrol more participants.[28] It is possibly more difficult to include people in a randomised controlled trial than a cohort study. Furthermore, average lesion characteristics and age of people with SCI have changed over the last 15 years.[29,30] Nowadays, relatively more people have incomplete lesions and are therefore less likely to be wheelchair dependent. In addition, relatively more people are older than 65 years, and therefore did not meet the inclusion criteria.

Measuring physical activity objectively with the activity monitor[a] had some limitations. First, due to technological challenges or user errors, the intended measurement period of 4 days was not always achieved. Secondly, for logistic reasons and to facilitate comparison of the measurements during inpatient rehabilitation and after discharge, the decision was made to only take measurements on weekdays. Therefore, it is unknown what effect the intervention had on weekend physical activity.

In summary, a behavioural intervention consisting of 13 individual sessions with a coach was effective in eliciting a behavioural change toward a more active lifestyle among people with subacute SCI. The addition of a behavioural intervention to regular rehabilitation and handcycle training resulted in 50% more wheeled physical activity. In order to promote an active lifestyle in this population that is generally known to be inactive and at risk of health complications, it is advised that a behavioural intervention is added to the regular care of people with subacute SCI.

**What is already known on this topic**: People with spinal cord injury often have low physical activity after discharge from their initial inpatient rehabilitation, despite regaining physical capacity and despite benefits of physical activity. Some behavioural interventions to increase physical activity are effective in people with chronic spinal cord injury.
**What this study adds**: In people with subacute spinal cord injury, adding a behavioural intervention during and for 6 months after the initial period of inpatient rehabilitation increases the amount of physical activity. The significant improvement in physical activity was still evident 1 year after discharge.



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