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Effectiveness of physical therapy interventions to improve the performance of motor tasks in patients with spinal cord injuries: Physical therapy approaches

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Abstract

Spinal cord injury (SCI) is a debilitating neurological condition with tremendous socioeconomic impact on affected individuals and the health care system. Physiotherapy for spinal cord injury rehabilitation focuses on optimizing mobility through exercise. Because every spinal cord injury is unique, every individual requires as a personalized rehabilitation plan. In Iran, there are a few scientific papers related to physiotherapy rehabilitation for people with spinal cord injury. The aim of this study was to effectiveness of physical therapy interventions to improve the performance of motor tasks in patients with spinal cord injuries.

Key words: Physiotherapy Rehabilitation, Spinal Cord Injury, Narrative Review

Introduction

Spinal cord injury (SCI) is a debilitating neurological condition with tremendous socioeconomic impact on affected individuals and the health care system [1]. Today, the estimated lifetime cost of an SCI patient is 2.35$ million per patient. According to the National Spinal Cord Injury Statistical Center, there are 12,500 new cases of SCI each year in North America [2]. More than 90% of SCI cases are traumatic and caused by incidences such as traffic accidents, violence, sports, or falls. The male-to-female ratio of 2:1 for SCI, which happens more frequently in adults compared to children [3]. Demographically, men are mostly affected during their early and late adulthood (3rd and 8th decades of life) while women are at higher risk during their adolescence (15-19 years) and 7th decade of their lives age distribution is bimodal, with a first peak involving young adults and a second peak involving adults over the age of 60 [4]. Those over 60 years of age who suffer SCI have considerably worse outcomes than younger patients their injuries usually resulting from falls and age-related bony changes [5].

The spinal cord is the major conduit through which motor and sensory information travel between brain and body. The spinal cord contains longitudinally oriented spinal tracts (white matter) surrounding central areas (gray matter) where most spinal neuronal cell bodies are located [6]. The grey matter is organized into segments comprising sensory and motor neuros. Axons from spinal sensory neuros enter and axons from motor neurons leave the spinal cord via segmental nerves or roots. The roots are numbered and named according to the foramina through which they enter/exit the vertebral column [7]. Each root receives sensory information from skin areas called dermatomes. Similarly, each root innervates a group of muscles called a myotome. The spinal column is divided into four regions: Cervical (7 vertebrae), thoracic (12 vertebrae), lumbar (5 vertebrae), and sacral (5 vertebrae) [8].

Physiotherapy for spinal cord injury rehabilitation focuses on optimizing mobility through exercise. Because every spinal cord injury is unique, every individual requires a personalized rehabilitation plan. A physiotherapist will assess one’s functional abilities following a spinal cord injury. Create a personalized exercise regimen, and help patients work towards realistic recovery goals [9].

This paper will go over what to expect with physiotherapy for spinal cord injury and why it’s such as essential part of the rehabilitation process.

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 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 [10]. 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 [11]. In contrast, the International Standards for the Neurological Classification of SCI 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 [12].

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 analyzing 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 [13]. Assessments are also used to provide an objective way of monitoring improvement over time. More standardized 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 standardized assessment that captures these constructs [14]. Of course, some standardized and objective assessments can also be used to identify underlying problems and guide treatment, particularly assessments of impairments. Standardized 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 [15]. 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 [16].

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 standardized assessments of activity limitations as there are assessments of impairments, and again some are generic assessments while others are specific to SCI [17]. The most commonly used assessments that are specific to SCI and physiotherapy include the Spinal Cord Independence Measure (SCIM) 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. 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. The WISCI is a 21-point scale that summarizes a person's ability to walk after taking into account need for assistance, orthoses or walking aids [19]. The WISCI also includes a 10-m timed walk test. Both the SCIM and WISCI have problems with their scoring algorithms, but nonetheless they are widely used in most SCI units around the world [20]. Despite the obvious importance of assessments for physiotherapists, there is no general international consensus on the most appropriate battery of physiotherapy-specific assessments [21]. However, representatives of the Spinal Cord Injury Group of the American Physical Therapy Association have put together a list of their recommendations, and the international SCI community has developed basic datasets for people with SCI. Some of the basic datasets are relevant to physiotherapists and include assessments that could be used to both guide treatment and monitor improvements over time [22].

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 randomized, controlled trials involving people with SCI [23]. 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) [24]. 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, mobilize in a wheelchair and use their upper limbs [25]. 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 [26].

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-randomized or poorly conducted trials in people with SCI; both of which often provide biased estimates of treatment effects [27]. 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 [28].

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 [29]. 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 scrutinize these interventions within clinical trials [30].

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.

Physiotherapy interventions to increase strength

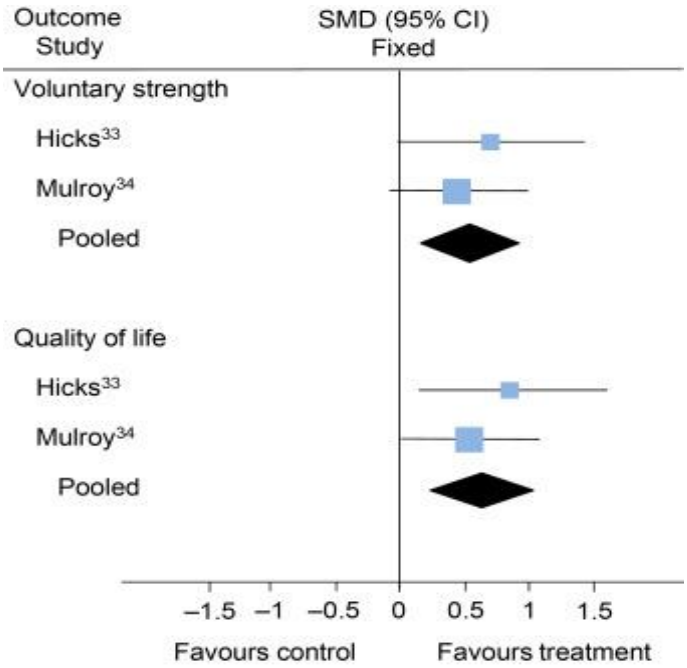
Weakness is the most obvious impairment that prevents people with SCI from performing motor tasks. Consequently, strength training interventions are widely administered by physiotherapists [31]. Limited strength in people with SCI can be neurologically induced, as seen in people with Grade 2 or 3 strength 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 neutrally 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-paralyzed muscles not only increases strength but also increases quality of life (Figure 1).

The situation is not so clear with partially paralyzed 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 paralyzed 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 paralyzed muscles can be attributed to physiotherapy interventions as opposed to natural recovery.



The optimal training paradigm to increase strength in partially paralyzed 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 resistance. It is also unclear whether strength training programs are enhanced by electrical stimulation.

Four randomized, controlled trials [36], [37], [38], [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 (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 paralyzed 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], [38] 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.

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 paralyzed muscles and not increases in strength of neurally intact muscles.

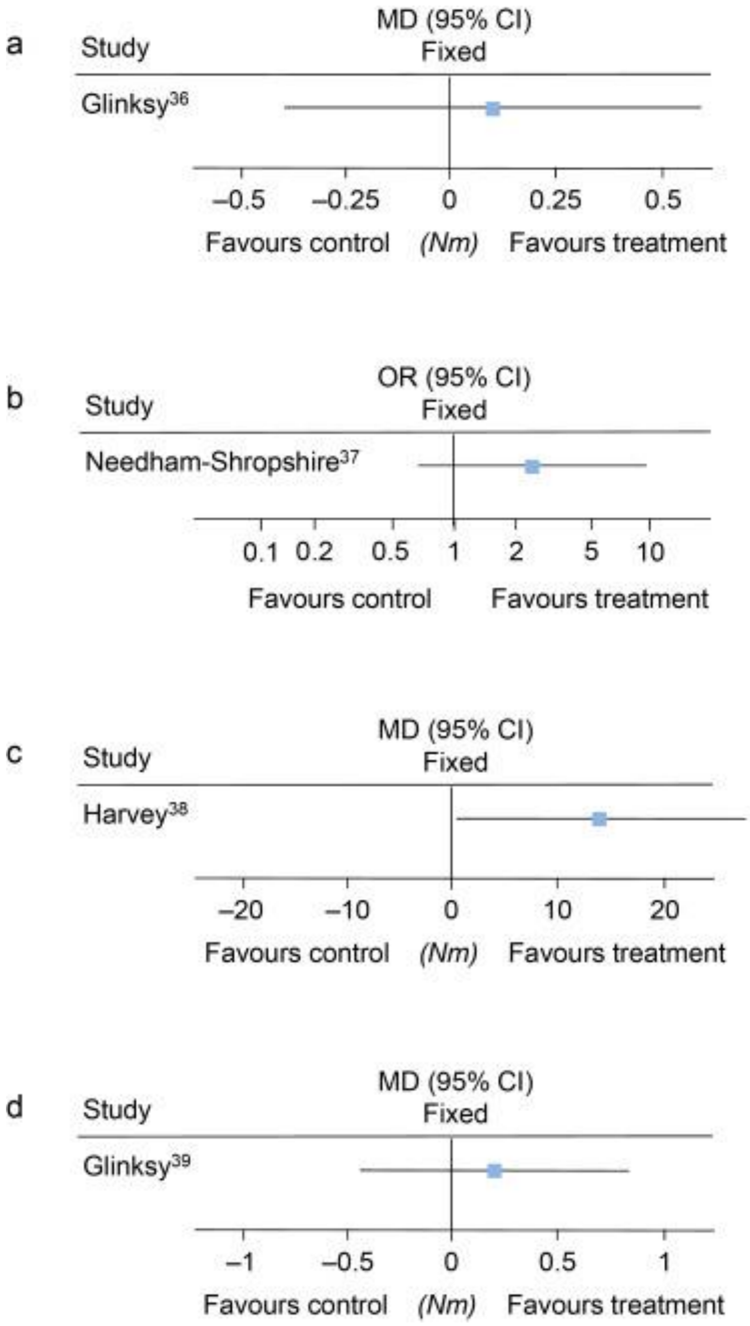


Figure 2. (a) Mean difference (MD) of the effect of electrical stimulation versus control on torque of partially paralyzed muscles in people with SCI. (b) Odds ratio (OR) of the effect of electrical stimulation versus control on upper limb American Spinal Injuries Association Impairment Scale A (AIS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

Interestingly, only two of these trials indicated a treatment effect on strength.[40], [47] The first trial compared robotic gait training with over ground 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). 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, [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 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 [53]. 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 practice 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 practice 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 over ground training?

The evidence about the superiority of treadmill training and robotic devices compared with over ground training comes from animal studies, some of which date back to the 1980s and show therapeutic effects of cyclic walking [54]. 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]. Non-randomized trials, single case studies or studies using historical controls also suggest that these treatments are therapeutic, particularly in those with motor incomplete lesions [55]. However, clinical trials have failed to replicate these promising results. Results of the six randomized, controlled trials involving 263 participants comparing treadmill training with over ground training.[42], [43], [44], [45], [45], 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 [56] (which does not include a recent trial) [57] and to the results of two clinical trials comparing robotic gait training with over ground gait training.[40], [46] These findings also parallel the results of similar trials in stroke [58] 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] 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]. 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 paralyzed legs, even if the chances of ultimately walking are slim. They argue that 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 rationalization. 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], There is clearly a need for some balance between the two positions.

Conclusions

The recent focus on neural plasticity and neural recovery following SCI has led to the emergence of a new term, 'activity-based therapy'. Activity-based therapy has been heralded by some as a novel approach to physiotherapy for people with SCI, yet it is surprisingly difficult to get a clear definition of what is meant by this term [59]. 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 [60]. However, it also includes 'developmental sequencing' exercises, strength training, and treadmill or robotic walking with or without electrical stimulation. Its proponents argue that it is novel because it focuses on optimizing 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. 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 over ground. 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. The emphasis must remain on high-quality trials to guide evidence-based physiotherapy for people with SCI.

References

1. W.P. Waring III, F. Biering-Sorensen, S. Burns, W. Donovan, D. Graves, A. Jha, et al. Review and revisions of the International Standards for the Neurological Classification of Spinal Cord Injury. J Spinal Cord Med., 33 (2010), pp. 346-352.
2. Chhabra HS. ISCoS Textbook on Comprehensive Management of Spinal Cord Injuries. Chhabra HS, ed. New Delhi: Wolters Kluwer; 2015.
3. H.S. Chhabra, L.A. Harvey, S. Muldoon, S. Chaudhary, M. Arora, D.J. Brown, et al. A global educational initiative of ISCoS. Spinal Cord., 51 (2013), pp. 176-182.
4. K.D. Anderson. Targeting recovery: priorities of the spinal cord-injured population. J Neurotrauma., 21 (2004), pp. 1371-1383.
5. L. Harvey. Management of spinal cord injuries: a guide for physiotherapists. Elsevier, London (2008).
6. G. Scivoletto, V. Di Donna. Prediction of walking recovery after spinal cord injury. Brain Res Bull., 78 (2009), pp. 43-51.
7. J.J. Van Middendorp, A.J. Hosman, A.R.T. Donders, M.H. Pouw, J.F. Ditunno Jr., A. Curt, et al. A clinical prediction rule for ambulation outcomes after traumatic spinal cord injury: A longitudinal cohort study. Lancet., 377 (2011), pp. 1004-1010.
8. J. Chu, L.A. Harvey, M. Ben, J. Batty, A. Avis, R. Adams. Physical therapists' ability to predict future mobility after spinal cord injury. J Neurol Phys Ther., 36 (2012), pp. 3-7.
9. L. Harvey, J. Chu, R. Adams, J. Batty, D. Barratt, S. Kwok. Accuracy of physiotherapists' predictions of one-year mobility for people with spinal cord injury. Physiother Theory Pract., 29 (2013), pp. 393-400.
10. L.A. Harvey, R. Adams, J. Chu, J. Batty, D. Barratt. A comparison of patients' and physiotherapists' expectations about walking post spinal cord injury: a longitudinal cohort study. Spinal Cord., 50 (2012), pp. 548-552.
11. L. Harvey, J.J. Wyndaele. Are we jumping too early with locomotor training programs? Spinal Cord., 49 (2011).
12. L. Harvey, M. Somers, J. Hastings, J. Bruce. The possible deleterious effects of therapy solely direct at neural plasticity and walking in people with serious spinal cord injury (letter to the editor). Arch Phys Med Rehabil., 92 (2011), p. 1924.
13. R.J. Marino, L. Jones, S. Kirshblum, J. Tal, A. Dasgupta. Reliability and repeatability of the motor and sensory examination of the international standards for neurological classification of spinal cord injury. J Spinal Cord Med., 31 (2008), pp. 166-170.
14. L. Harvey, D. Graves. International Standards for the Neurological Classification of Spinal Cord Injury. J Physiother., 57 (2011), p. 129.
15. Catz, M. Itzkovich, F. Steinberg, O. Philo, H. Ring, J. Ronen, et al. The Catz-Itzkovich SCIM: a revised version of the Spinal Cord Independence Measure. Disabil Rehabil., 23 (2001), pp. 263-268.

16. M. Itzkovich, I. Gelernter, F. Biering-Sorensen, C. Weeks, M.T. Laramee, B.C. Craven, et al. The Spinal Cord Independence Measure (SCIM) version III: reliability and validity in a multi-center international study. Disabil Rehabil., 29 (2007), pp. 1926-1933.

17. J.F. Ditunno Jr., P.L. Ditunno, G. Scivoletto, M. Patrick, M. Dijkers, H. Barbeau, et al. The Walking Index for Spinal Cord Injury (WISCI/WISCI II): nature, metric properties, use and misuse. Spinal Cord., 51 (2013), pp. 346-355.

18. L.A. Harvey, K.D. Anderson. The spinal cord independence measure. J Physiother., 61 (2015), p. 99.

19. C. Fekete, I. Eriks-Hoogland, M. Baumberger, A. Catz, M. Itzkovich, H. Luthi, et al. Development and validation of a self-report version of the Spinal Cord Independence Measure (SCIM III). Spinal Cord., 51 (2013), pp. 40-47.

20. L. Harvey, R. Marino. The Walking Index for Spinal Cord Injury Aust J Physiother., 55 (2009), p. 66.

21. M.S. Alexander, K.D. Anderson, F. BieringSorensen, A.R. Blight, R. Brannon, T.N . Bryce, et al. Outcome measures in spinal cord injury: recent assessments and recommendations for future directions. Spinal Cord., 47 (2009), pp. 582-591.

22. F. Biering-Sørensen, S. Charlifue, M. DeVivo, V. Noonan, M. Post, T. Stripling, et al. International Spinal Cord Injury Data Sets. Spinal Cord., 44 (2006), pp. 530-534.

23. F. Biering-Sørensen, A. Bryden, A. Curt, J. Friden, L.A. Harvey, M.J. Mulcahey, et al. International Spinal Cord Injury Upper Extremity Basic Data Set. Spinal Cord., 52 (2014), pp. 652-657.

24. F. Biering-Sørensen, A.S. Burns, A. Curt, L.A. Harvey, M. Jane Mulcahey, P.W. Nance, et al. International Spinal Cord Injury Musculoskeletal Basic Data Set. Spinal Cord., 50 (2012), pp. 797-802.

25. L. Harvey, C.M. Lin, J. Glinsky, A. De Wolf. The effectiveness of physical interventions for people with spinal cord injuries: a systematic review. Spinal Cord., 47 (2009), pp. 184-195

26. L.A. Harvey, J.V. Glinsky, J.L. Bowden, M. Arora. How well do randomized controlled trials of physical interventions for people with spinal cord injury adhere to the CONSORT guidelines? An analysis of trials published over a 10-year period. Spinal Cord., 52 (2014), pp. 795-802.

27. S.A. Van Langeveld, M.W. Post, F.W. Van Asbeck, M. Gregory, A. Halvorsen, H. Rijken, et al. Comparing content of therapy for people with a spinal cord injury in postacute inpatient rehabilitation in Australia, Norway, and the Netherlands. Phys Ther., 91 (2011), pp. 210-223.

28. L.A. Harvey. Randomized controlled trials do not always give the results we want but that doesn’t mean we should abandon randomised controlled trials. Spinal Cord., 53 (2015), p. 251.

29. S.A. Van Langeveld, M.W. Post, F.W. Van Asbeck, P. Ter Horst, J. Leenders, K. Postma, et al. Contents of physical therapy, occupational

therapy, and sports therapy sessions for patients with a spinal cord injury in three Dutch rehabilitation centres. Disabil Rehabil., 33 (2011), pp. 412-422

30. J. Munn, R.D. Herbert, M.J. Hancock, S.C. Gandevia. Resistance training for strength: effect of number of sets and contraction speed. Med Sci Sports Exerc., 37 (2005), pp. 1622-1626.
31. A.L. Hicks, K.A. Martin, D.S. Ditor, A.E. Latimer, C. Craven, J. Bugaresti, et al. Long-term exercise training in persons with spinal cord injury: effects on strength, arm ergometry performance and psychological well-being. Spinal Cord., 41 (2003), pp. 34-43.
32. S.J. Mulroy, L. Thompson, B. Kemp, P.P. Hatchett, C.J. Newsam, D.G. Lupold, et al. Strengthening and optimal movements for painful shoulders (STOMPS) in chronic spinal cord injury: A randomized controlled trial. Phys Ther., 91 (2011), pp. 305-324.
33. J.F. Ditunno, M.E. Cohen, W.W. Hauck, A.B. Jackson, M.L. Sipski. Recovery of upper-extremity strength in complete and incomplete tetraplegia: a multicenter study. Arch Phys Med Rehabil., 81 (2000), pp. 389-393.
34. J. Glinsky, L. Harvey, P. van Es, S. Chee, S.C. Gandevia. The addition of electrical stimulation to progressive resistance training does not enhance the wrist strength of people with tetraplegia: a randomized controlled trial. Clin Rehabil., 23 (2009), pp. 696-704.
35. B.M. Needham-Shropshire, J.G. Broton, T.L. Cameron, K.J. Klose. Improved motor function in tetraplegics following neuromuscular stimulation-assisted arm ergometry. J Spinal Cord Med., 20 (1997), pp. 49-55.
36. L.A. Harvey, C. Fornusek, J.L. Bowden, N. Pontifex, J. Glinsky, J.W. Middleton, et al. Electrical stimulation plus progressive resistance training for leg strength in spinal cord injury: A randomized controlled trial. Spinal Cord., 48 (2010), pp. 570-575.
37. J. Glinsky, L. Harvey, M. Korten, C. Drury, S. Chee, S.C. Gandevia. Short-term progressive resistance exercise may not be effective for increasing wrist strength in people with tetraplegia: a randomised controlled trial. Aust J Physiother., 54 (2008), pp. 103-108.
38. M. Alcobendas-Maestro, A. Esclarin-Ruz, R.M. Casado-Lopez, A. Munoz-Gonzalez, G. Perez-Mateos, E. Gonzalez-Valdizan, et al. Lokomat robotic-assisted versus overground training within 3 to 6 months of incomplete spinal cord lesion: randomized controlled trial Neurorehabil Neural Repair., 26 (2012), pp. 1058-1063.
39. L. Harvey, S. Dunlop, L. Churilov, Y. Hsueh, M. Galea. Early intensive hand rehabilitation after spinal cord injury (“Hands On”): a protocol for a randomised controlled trial. BMC Trials., 12 (2011), pp. 1-9.
40. B. Dobkin, D. Apple, H. Barbeau, M. Basso, A. Behrman, D. Deforge, et al. Weight-supported treadmill vs over-ground training for walking after acute incomplete SCI. Neurology., 66 (2006), pp. 484-493.
41. N. Alexeeva, C. Sames, P.L. Jacobs, L. Hobday, M.M. Distasio, S.A. Mitchell, et al. Comparison of training methods to improve walking in persons with chronic

spinal cord injury: a randomized clinical trial. J Spinal Cord Med., 34 (2011), pp. 362-379.

42. E.C. Field-Fote, K.E. Roach. Influence of a locomotor training approach on walking speed and distance in people with chronic spinal cord injury: a randomized clinical trial Phys Ther., 91 (2011), pp. 48-60.
43. N.J. Postans, J.P. Hasler, M.H. Granat, D.J. Maxwell. Functional electrical stimulation to augment partial weight-bearing supported treadmill training for patients with acute incomplete spinal cord injury: A pilot study. Arch Phys Med Rehabil., 85 (2004), pp. 604-610
44. T.G. Hornby, D.D. Campbell, D.H. Zemon, J.H. Kahn. Clinical and quantitative evaluation of robotic-assisted treadmill walking to retrain ambulation after spinal cord injury. Top Spinal Cord Inj Rehabil., 11 (2005), pp. 1-17.
45. K.S. Beekhuizen, E.C. Field-Fote. Sensory stimulation augments the effects of massed practice training in persons with tetraplegia. Arch Phys Med Rehabil., 89 (2008), pp. 602-608.
46. J. Glinsky, L. Harvey, P. van Es. Efficacy of electrical stimulation to increase muscle strength in people with neurological conditions: A systematic review. Physiother Res Int., 12 (2007), pp. 175-194.
47. J.C. Baldi, R.D. Jackson, R. Moraille, W.J. Mysiw. Muscle atrophy is prevented in patients with acute spinal cord injury using functional electrical stimulation. Spinal Cord., 36 (1998), pp. 463-469
48. M. Lee, M.C. Kiernan, V.G. Macefield, B.B. Lee, C.S.Y. Lin. Short-term peripheral nerve stimulation ameliorates axonal dysfunction after spinal cord injury. J Neurophysiol., 113 (2015), pp. 3209-3218.
49. W. Young. Electrical stimulation and motor recovery. Cell Transplant., 24 (2015), pp. 429-446
50. L.A. Harvey, R.D. Herbert. Muscle stretching for treatment and prevention of contracture in people with spinal cord injury. Spinal Cord., 40 (2002), pp. 1-9.
51. O.M. Katalinic, L.A. Harvey, R.D. Herbert. Effectiveness of stretch for the treatment and prevention of contractures in people with neurological conditions: a systematic review. Phys Ther., 91 (2011), pp. 11-24.
52. A.M. Gentile. Skill acquisition: action, movement, and neuromotor processes. J.H. Carr, R.B. Shepherd (Eds.), Movement science: Foundations for physical therapy in rehabilitation, Aspen Publishers, Rockville, MD (2000), pp. 111-187.
53. R.G. Lovely, R.J. Gregor, R.R. Roy, V.R. Edgerton. Effects of training on the recovery of full-weight-bearing stepping in the adult spinal cat. Exp Neurol., 92 (1986), pp. 421-435.
54. Wernig, S. Muller, A. Nanassy, E. Cagol. Laufband therapy based on “rules of spinal locomotion” is effective in spinal cord injured persons. Eur J Neurol., 7 (1995), pp. 823-829.
55. J. Mehrholz, J. Kugler, M. Pohl. Locomotor training for walking after spinal cord injury. Cochrane Database Syst Rev., 11 (2012), p. CD006676.

56. J.R. Wolpaw. Treadmill training after spinal cord injury: good but not better. Neurology., 66 (2006), pp. 466-467.
57. A.L. Behrman, S.J. Harkema. Physical rehabilitation as an agent for recovery after spinal cord injury. Phys Med Rehabil Clin N Am., 18 (2007), pp. 183-202
58. E.E. Field-Fote. Saying what we mean, and meaning what we say. J Neurol Phys Ther., 38 (2014), pp. 205-206.
59. J.H. Carr, R.B. Shepherd. A motor relearning programme for stroke. Heinemann Medical, London (1982).
60. I.E. Eriks-Hoogland, S. de Groot, M.W. Post, L.H. van der Woude. Passive shoulder range of motion impairment in spinal cord injury during and one year after rehabilitation. J Rehabil Med, 41 (2009), pp. 438-444.