Chapter 6

Role of Gait Training in Recovery of Standing and Walking in Subjects with Spinal Cord Injury

Mokhtar Arazpour, Guive Sharifi,
Mohammad Ebrahim Mousavi and Maryam Maleki

Additional information is available at the end of the chapter

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Abstract

Gait training has an important role in rehabilitation of standing and walking in spinal cord injury (SCI) patients. There were different types of gait training in these subjects. Both the body weight support treadmill training and robotic-assisted and robotic exoskeleton are effective and secure methods for gait training and improving the energy demand and metabolic cost in SCI patients in different level of injury. The powered exoskeletons can provide patients with SCI the ability to walk with the lowest energy consumption. The powered exoskeleton's energy consumption and speed of walking depend on the training duration. Based on different types of gait training methods, training time, and other affected parameters, the aim of this chapter was to evaluate the role of gait training in recovery of standing and walking in SCI patients.

Keywords: spinal cord injury, gait training, standing, walking

1. Introduction

The act of learning how to walk (as a child, or more frequently, after sustaining an injury or disability) is so-called **gait training** or **gait rehabilitation**. In this chapter, we focus on gait training after spinal cord injury (SCI). The purpose of gait training for subjects with SCI is usually to increase walking endurance and to decrease subject's dependency. Standing and walking can help to prevent contractures of the lower limb joints, as well as osteoporosis, spasticity, bed sores and edema, complete discharge of bladder, and prevention of bladder infection in subjects with SCI [1–4].

Spinal cord injury is spinal cord damaging that causes changes in function, most frequently and importantly, disruption in lower limb motor and sensation. Inability to walk is the most important limitation for affected patients [5]. Among lots of serious problem which patients encounter with, but after injury the first question is "will I ever walk again?" [6]. As a result, retraining the affected patients to achieve walking ability is important.

The main determinants of normal gait are [7]:

- Stability and posture,
- Range of motion (ROM),
- Muscle strength,
- Co-ordinated motor control,
- Muscle tone,
- Proprioception,
- Vision,
- Cognition,
- Aerobic capacity out of which the first six factors are impaired in spinal cord injured individuals.

In patients with SCI, there are no main determinants of normal gait, but in recent years, there have been advancements in how the patients can increase the ability to walk. Rehabilitation procedures should focus on the development of outcome by using the neuroplasticity and by using a functional training.

Lovely et al. in 1990 demonstrated neuronal circuits below the level of lesion become activated by an appropriate afferent input. They established that stepping practice plays an important role in training [8]. When the practice of stepping is accomplished, walking can be done more effective than when it is not practiced. In spinal cord, when a motor task wants to be recognized in neural circuit, it should be practiced appropriately and sufficiently. The name of this process is training [9]. De Leon et al. in 1998 and Wirz et al., 2001 stated that appropriate afferent input activate neuronal networks below the level of injury in a SCI patients, and activated neural network generate electromyography activity for suitable function (even in complete SCI without supraspinal input) [10, 11]. Dietz et al. in different experiments in human and animals revealed externally assisted walking, with tools and equipment or therapist, when appropriate afferent input will drive to spinal cord, a locomotor pattern will train and muscle activity (EMG) will be turned on even in complete SCI; however, muscle activity in complete SCI is low in comparison with healthy subjects but muscle EMG will increase by practicing more and more during training sessions [12].

One of the important afferent inputs is foot load receptor input. Researchers perceive the importance of these kinds of afferent input when they use externally assisted walking while patients are unloading. In this experiment, they understand unloading does not activate muscle EMG activity and they claim that, body unloading and reloading are considered to be of crucial importance to convince training effects upon the neurological locomotor centers,

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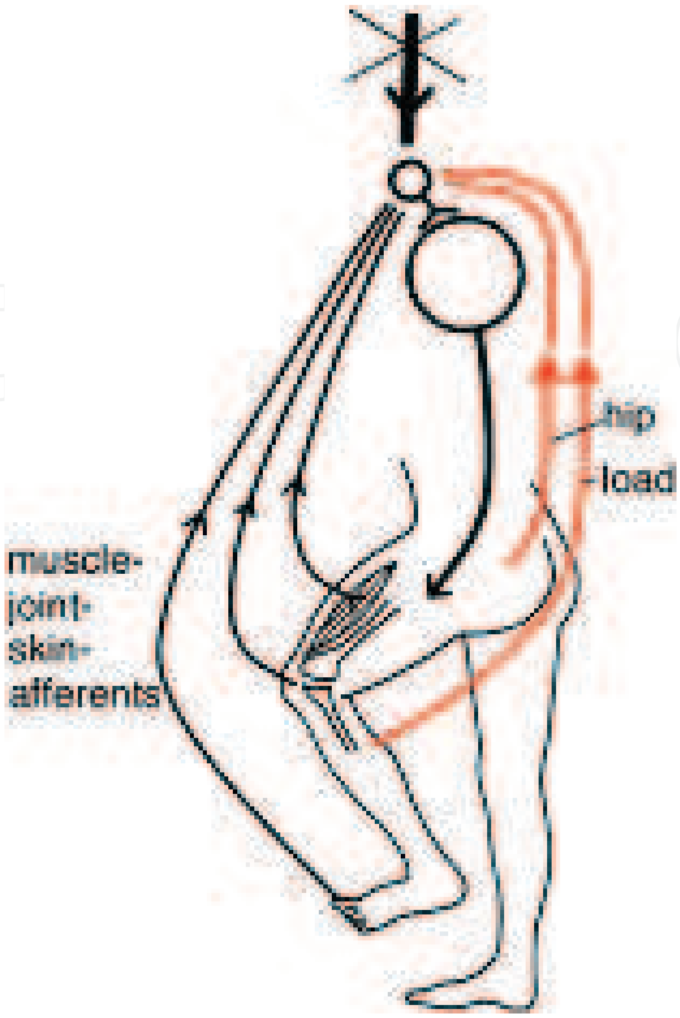

Figure 1. Schematic drawing of the afferent input from load- and hip joint [14].

because the afferent input from foot pressure during the stance phase is essential for the activation of spinal neuronal network (**Figure 1**) [13]. Dietz in 2008 suggested that another important input after foot contact pressure is proprioceptive input from extensor hip muscles. Foot sole mechanoreceptor with hip extensor muscles proprioception provides load information (**Figure 1**) [13].

2. Gait rehabilitation interventions following spinal cord injury

Until now, many therapeutic strategies have been developed for promoting locomotor activity of SCI subjects ranged from those that compensate for weakened or lost function (e.g. orthotic gait training) to strategies based on the concepts of central nervous system (CNS) plasticity (e.g. Erigo therapy and body weight–supported tread mill training) [15, 16]. Strategies that are based on the concept of CNS plasticity have shown improvement and enhancement in walking ability of SCI subjects through implementing the task-specific sensory input and repetitive and intensive gait therapy [17, 18]. These strategies will be explained as following.

3. Early gait rehabilitation interventions after spinal cord injury (Erigo therapy)

SCI subjects, in acute stages, are disposed to orthostatic hypotension occurrences while transferred from a horizontal to an upright position due to the lack of sympathetic activity and also leg muscle contractions that finally lead to delay in starting the functional gait training [18, 19]. On the other hand, the mobilization and verticalization of SCI patients in acute care with limited or no capacity for cooperation can be very challenging. One approach to decrease the orthostatic hypotension incidences is utilizing tilt table. Many limitations related to the use of traditional tilt table have been reported such as no leg movements, limited training duration due to the lack of patient's cardiovascular stability and excessive labor load on therapist for passive movements. Therefore, for overcoming of such limitations a novel, robotic tilt table so-called Erigo was designed and developed, which offered a locomotion therapy at a very early stage of rehabilitation. These types of approaches through utilizing a safe mobilization and intensive sensorimotor stimulation, ambulates the lower extremity, and suggests a wide range of positive impacts and functions to enhance early rehabilitation of SCI patients [18–20].

The design and construction of the "Erigo" was based on the conventional tilt table but combines gradual verticalization plus robotic leg movement's therapy and functional electrical stimulation [18] (**Figure 2**). The main superiority of "Erigo" to the traditional tilt table was utilizing the robotic leg movement and the cyclic leg loading that produce critical afferent stimuli for the central nervous system [18, 20, 21]. These afferent stimuli result in muscle activation, improved muscle pump function and venous return, which eventually result in improved cardiovascular stability in SCI subjects. There are a few studies about the efficacy of "Erigo" following spinal cord injury [18, 22, 23]. According to the previous research by Colombo et al., using Novel tilt table (tilted to 60° upright position) in five subjects with complete SCI (ASIA impairment scale A between C4 and C7) resulted in the increase of blood pressure and after stopping the automated movement, the mean arterial pressure decreased statistically significant($P < 0.0001$) [14]. Although this study showed the positive effects of passive movements of leg through using "Erigo" therapy on circulatory system in SCI patients, it has to be stated that further studies are necessary to test this type of approach in a larder patients group of SCI with different level of injury and also in the long term to indicate the direct effects of "Erigo" therapy.

Also Laubacher et al. indicated that the "Erigo" therapy is practical for respiratory and cardiopulmonary training and evaluation of incomplete SCI subjects and they found it was a tolerable and implementable approach [22]. Another approach in the rehabilitation of SCI subjects is combining the tilt table with vibrating foot plates (whole-body vibration) that focus on the activation of muscular and vascular systems. Herrero et al., found that whole body vibration (WBV) is an effective approach to enhance leg blood flow and to stimulate muscle activity in SCI subjects; therefore, they concluded that this approach could be incorporated in the rehabilitation programs of SCI subjects. So in future studies, we need to compare the efficacy of Erigo therapy and whole body vibration (WBV) on orthostatic, blood pressure, and EMG in subjects with SCI [24].

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Figure 2. Erigo components.

Also integrating functional electrical stimulation (FES) into "Erigo" provides more physiological and clinical benefits (**Figure 3**). The nerve endings are stimulated through attaching electrodes to the skin, which results in contraction and activation of muscles. Many positive effects have been reported by using of "Erigo" plus FES like improving in the cardiovascular system and metabolism condition, decreasing spasticity, improving the muscle tone, reducing long-term consequences due to the lack of muscle activity, inducing functional movements, increasing cardiovascular stability during upright position, and promoting the orthostatic tolerance by enhancing venous return in individual with SCI [18, 22, 25, 26]. Thrasher et al. compared the effects of isometric FES and dynamic FES on cardiovascular parameters on an active tilt-table stepper in 16 young and healthy adults. They stated that isometric FES led to short-term increases in blood pressure and also heart rate, but dynamic FES maintained increase in blood pressure over the long term. They postulated that however FES has potential to counteract orthostatic stress it should be combined with movements of leg [27]. In a pilot study, Yoshida et al. found that through applying FES cyclically to the leg muscles of 10 SCI subjects at T6 or higher, they could better retain their blood pressure. Although FES and

Figure 3. Functional electrical stimulation synchronized with leg cycling in "Erigo".

passive stepping by Erigo achieves this function by inducing venous return, passive stepping was less effective than FES in this study [23]. Finally, many studies are needed to extend these findings to the community of people with SCI with different levels of injury.

4. Body weight–supported treadmill training approaches after spinal cord injury

The most outstanding strategy for regaining the walking ability in SCI subjects is body weight–supported treadmill training (BWSTT) [16, 26, 28]. Traditionally, BWSTT device supported some of the SCI patient's body weight by using a harness, as therapists manually assist their legs via the stepping movement on a treadmill. Although, it has been shown that such interventions could enhance and promote locomotor activity in SCI subjects, according to the previous researches, traditional gait therapy had many disadvantages such as excessive labor load on therapists, confined training duration, and gait pattern without any feedback for patients (**Figure 4**) [17]. Therefore, body weight–supported treadmill training using lower extremity robotic exoskeleton (e.g. Lokomat) was designed and developed and initially implemented for SCI rehabilitation. The BWSTT with robotics exoskeleton has originated from the central pattern generator (CPG) and is a secure and functional intervention that allows gait training by covering the limitations of conventional gait therapy [16, 29].

One of the famous robotics exoskeleton use in conjunction with the BWSTT is the Lokomat (Hocoma AG, Volketswil, Switzerland), which is a bilateral robotic orthosis, worn by patients, and attaches to a treadmill frame to provide powered assistance at the hip and knee in the sagittal plane, while a therapist can check the system and regulate assistance as necessary (**Figure 5**) [17, 28].

The Lokomat has been demonstrated to be effective in producing more normal walking patterns and promoting walking ability in subjects with incomplete SCI. Generally, applying the robotic

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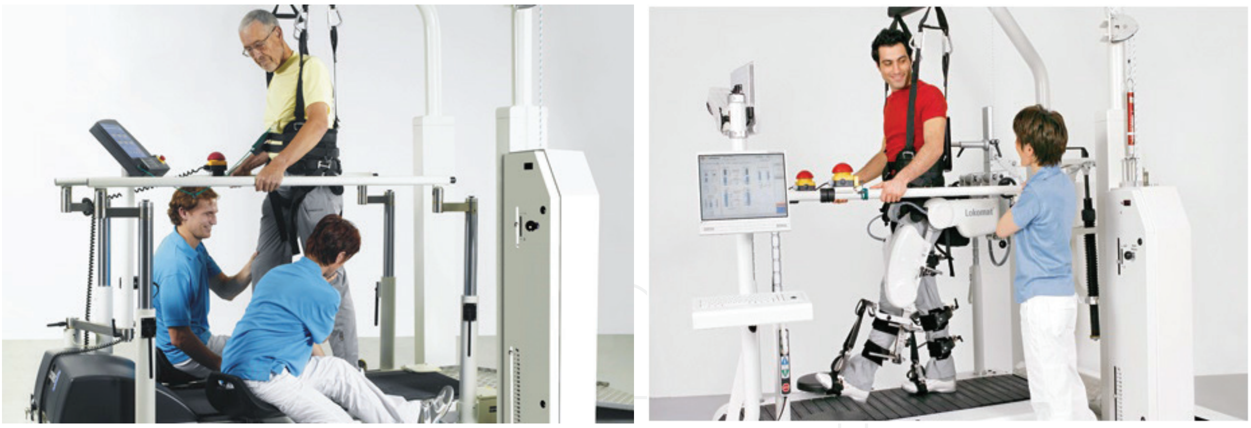

Figure 4. Traditional BWSTT (A) V.S. BWSTT plus robotic exoskeleton (B).

Figure 5. Lokomat components.

exoskeleton device in conjunction with the BWSTT, in gait rehabilitation procedure, could potentially accelerate recovery of walking ability in individual following SCI through enhancing the duration of training and reducing the labor load on physical therapists [17, 28, 29].

5. Orthotic gait training

There are different types of orthoses and assistive devices for standing and walking in complete and incomplete spinal cord injury subjects [30]. This type of intervention ranged from solid ankle foot orthosis to reciprocating gait orthoses and powered gait orthoses, which were used to low incomplete level of spinal cord injury and high complete or incomplete level of injury [31]. In general concept, all orthoses were used with walking aid for ambulation. Several factors influenced the providing walking ability via orthoses in the SCI subjects, which gait training is the important of them [32].

6. Orthotic gait training of SCI subjects with the mechanical orthoses

There were different types of mechanical orthoses such as hip-knee-ankle-foot orthosis, reciprocating gait orthosis (RGO) (**Figure 6**), hip guidance orthosis, and medial linkage orthoses (e.g. walkabout orthosis (WO), Primewalk orthosis (**Figure 7**)) to provide standing and walking in subjects with SCI [30]. Several studies evaluated this type of orthoses on walking ability in these subjects [30]. Based on the evaluation of the energy expenditure, Harvey et al. demonstrated that energy consumption of walking with the WO were greater than walking with the isocentric reciprocating gait orthosis (IRGO) in SCI subjects with T9–12 paraplegia [33]. In addition in another study, Harvey et al. demonstrated that stand up and sit down with WO was easier than IRGO, but IRGO provided faster and more independent ambulation [34]. In comparison of the attitude of subjects with SCI when using WO and the IRGO, Harvey et al. reported few

Figure 6. Isocentric reciprocating gait orthosis [32].

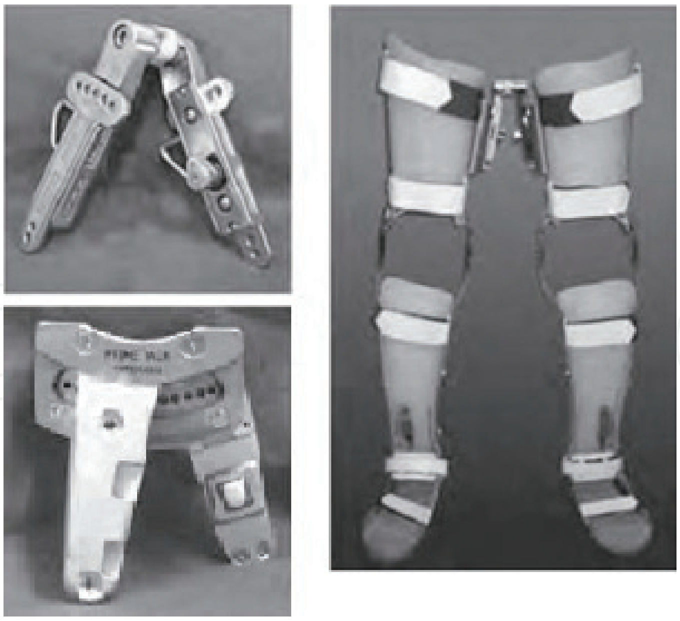

Figure 7. Walkabout orthosis and Primewalk orthosis.

subjects used orthosis more than once every 2 weeks, and SCI individuals were primarily wearing the orthoses for therapeutic aims [35]. To evaluate the influence of Primewalk orthosis and walkabout orthosis in improving the walking performance in subjects with SCI, Ongio et al. demonstrated the Primewalk orthosis had better effect in walking efficiency than that of the Walkabout orthosis [36].

Training time announced different in this field between 2 until 12 weeks. Longitudinal training program demonstrated the better results on the improvement of walking parameters. The maximum rate of the speed of walking reported from 0.13 to 0.63 m/s, which is 13–57% of the optimal speed (1.1 m/s) required for successful community ambulation [37]. Home or indoor mobility for exercise, upright posture, and standing reported final benefits of orthotics gait rehabilitation [38, 39].

The successful orthotic gait rehabilitation in SCI subjects related to the several factors included well-motivated, with complete level of injury at T9 or below, incomplete level of injury, postural control, and [39–41] good upper extremity strength, as well as less spasticity and low level contractures [42], reduced thoracolumbar mobility, back pain, or any musculoskeletal problems that influenced standing upright [33, 43]. Orthotic gait rehabilitation can be influenced by the acceptance of orthoses. In other words, acceptance of orthoses may be influenced by donning and doffing time, the best time for donning and doffing of orthosis should be less than 5 minutes [31].

7. Orthotic gait training of SCI subjects with powered gait orthoses

Providing gait training in different environments such as clinic, home, or community announced as the main benefit of wearing powered gait orthosis [3]. Only limited PGOs are currently commercially available to the public and therefore would be able to be used

Figure 8. The HAL-5 type-C (hybrid assistive limb).

Figure 9. The ReWalk powered orthosis (Argo Medical Technologies).

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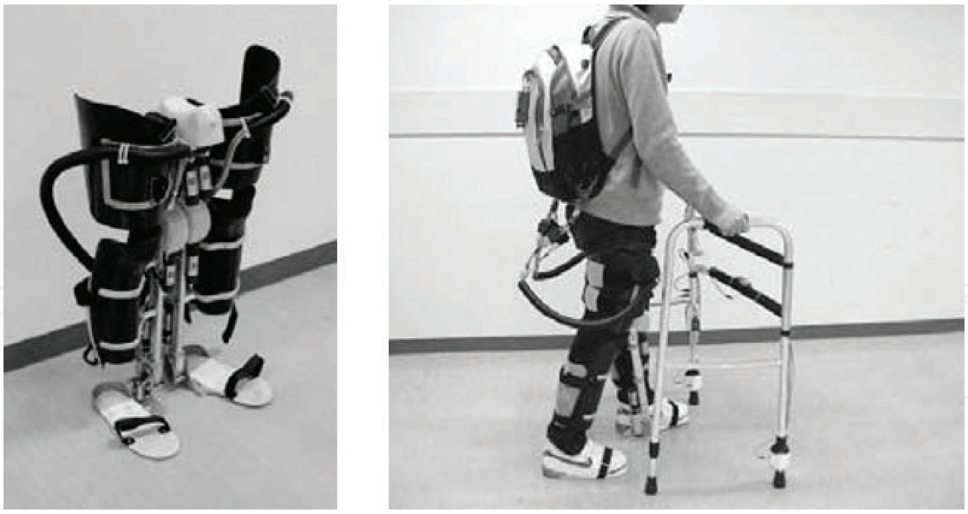

Figure 10. The wearable power assist locomotor.

in the field in SCI subjects. The concept of using PGOs is the reduction of energy demand in uses and reduces loads on the upper limb joints.

The HAL-5 Type-C (hybrid assistive limb) (**Figure 8**), the ReWalk powered orthosis (Argo Medical Technologies) (**Figure 9**), the wearable power assist locomotor (**Figure 10**), and the eLEGS-powered orthosis (Berkeley Bionics) (**Figure 11**) are commercially powered orthoses for ambulation in SCI subjects.

In the evaluation of the gait training with the HAL-6LB on the SCI subject for 8 days, for 2 hours per day, Tsukahara et al. reported that walking speed and cadence were 0.11 m/s and

Figure 11. The eLEGS-powered orthosis (Berkeley Bionics).

20 steps/minutes, respectively [44]. In the evaluation of Rewalk exoskeleton on safety and tolerance in SCI patients, Zeilig et al. reported that mean time to walk 10 m was 47 seconds following training when using the Rewalk [45]. In another study, distance walked for 50–100 m announced between 5 and 10 minutes continually. The mean walking speed was 0.25 m/s [46]. In the evaluation of the wearable power assist locomotor orthosis (WPAL) on walking, physiological cost index (PCI) and muscle activity of the upper extremities in SCI subjects, Tanabe et al. reported all patients walked independently with the new powered device. The increased walking duration and distance of walking and reduction of the PCI and muscle activity of upper limbs with the WPAL compared to that the Primewalk orthosis [47]. Based on the literature in this field, we can conclude that PGOs can enable safe walking and reduce energy expenditure compared to mechanical orthoses in SCI subjects.

8. Orthotic gait training with hybrid system (bracing combined with FES) in SCI

High level of energy demand and high effort and loads on the upper limb joints announced the main complication of the orthotics gait rehabilitation with mechanical orthoses. Combination of the mechanical orthoses and FES innovated to improve gait parameters and reduce the loads and energy demand in SCI subjects. The main concept of the using this type of approach announced trunk and hip stability and facilitate forward progression.

Different studies in this field evaluated the hybrid systems on the walking capacity in SCI subjects [38, 40, 48, 49]. Distance walked was announced as 180–1400 m in these studies [38, 40, 48, 49]. Although there was no significant improvement in the walking speed, but improvement in the distance walked was observed in trails in this field. The rate of the distance walked was announced between 3 and 400 m when the FES or orthoses were trained alone [38, 40, 48]. In subjects with incomplete level of spinal cord injury, the gait training with hybrid systems provided improvement in ambulation capacity compared to bracing or FES using alone [50].

9. Orthotic gait training protocol

The training approach announced different among the studies on SCI population [51]. Training protocol has been performed different for powered and mechanical orthoses. Based on the time of the training program, five studies had a shorter training period [26, 45, 52–55], while several weeks to months were reported in other studies [32, 51]. Training protocol was being done on the different surfaces including sidewalk, grass, or stairs [56–58]. Yong et al. used the training protocol with powered gait orthosis on the treadmill to increase confidence of SCI subjects and improvement of the walking speed on them [59]. While in using powered gait orthosis, Arazpour et al. [60] performed upper extremity strengthening and lower extremity stretching as the main section of the training during orthotic gait rehabilitation. Further study on how different training programs affected the walking ability outcomes in the SCI patients will be beneficial in this field.

Orthotic training in SCI subjects can be reduced fatigue and fear of falling and increased the stepping [61]. It was announced that after training program, SCI subjects had walking ability and performance of activity of daily living. The SCI subjects may have less energy demand during walking with orthoses compared to without orthotic gait training condition [32].

10. Positive results of walking in SCI subjects

Complications of SCI such as spasticity, joint contractures, pressure sores, osteoporosis, and urinary tract infections may be present in subjects with SCI [1, 2]. Standing and walking provides physiological and psychological benefits for individuals with SCI [3]. A reduction of bed sores, osteoporosis, spasticity, contractures, and improvement of bladder and bowel functions have all been announced after standing and walking in subjects with SCI [1, 4]. Orthotic gait training is the intervention, which can help in SCI subjects.

Future study in this field must be focused on the following terms:

- The effect of orthotics gait training on the quality of life in SCI subjects
- The effect of orthotics gait training on the electromyography of the lower limb muscles
- Comparison between orthotics gait training with RGOs and powered orthosis on the walking parameters and other related parameters

Author details

Mokhtar Arazpour[1]*, Guive Sharifi[2], Mohammad Ebrahim Mousavi[1] and Maryam Maleki[1]

*Address all correspondence to: m.arazpour@yahoo.com

1 Department of Orthotics and Prosthetics, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran

2 Department of Neurosurgery, Shahid Beheshti University of Medical Sciences, Tehran, Iran

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