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Locomotive Training for Motor-Incomplete SCI in the Sub-Acute Setting: A Case Study

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Abstract

Background: Each year there are about 17,000 new cases of spinal cord injury (SCI) in the United States. For individuals who suffer a SCI, the restoration of walking consistently ranks as a top priority. Currently, there is strong evidence to support the use of locomotive training for recovery of ambulation following an incomplete spinal cord injury in the sub-acute setting. The purpose of this case report is to demonstrate the application of multiple locomotive training interventions and discuss recommendations for locomotive training following a motor-incomplete SCI. **Case description:** The patient was a 32-year old male 4 months post motor-incomplete spinal cord injury with an ASIA C classification. His injury occurred at the spinal level C5. At baseline, he presented with a Walking Index for Spinal Cord Injury (WISCI) II score of 6 and was unable to complete the 10-meter walk test (10MWT). **Interventions:** In this study, multiple locomotive training interventions (Ekso GT, Zero-G dynamic body weight support, HydroWorx, and over ground training) were implemented to facilitate task-specific, massed practice gait training. These interventions were strategically employed to maximize the training dose to optimally influence ambulation recovery. **Outcome Measures:** The primary outcome measures used in this case were the WISCI II and the 10MWT. The secondary outcome measure used was walking distance. At discharge, the patient demonstrated clinically important improvements in all three outcomes. **Discussion:** This report was able to demonstrate the utilization of several locomotive training techniques and provide clinicians examples of possible gait training parameters following SCI. There is currently not enough data to synthesize gait training prescription guidelines for individuals with sub-acute SCI thus driving the need for additional large-scale data collection.

Background

In the United States, there are about 17,000 new cases of spinal cord injury (SCI) each year. The number of people in the U.S. who are alive in 2016 who have SCI has been estimated to be approximately 282,000 persons [1]. Following a SCI there is often a drastic change in function, which can equate to life-changing consequences for the individual and their families. The inability to walk can impact the identity of an individual and can be emotionally and psychologically devastating. For these reasons and more, the restoration of walking consistently ranks as the most important priority for an individual following a SCI [2,3].

Following incomplete injury to the spinal cord, some degree of spontaneous recovery is frequently observed even without physical rehabilitation. However, the current literature suggests that physical rehabilitation and pharmacological interventions can significantly influence the recovery and reorganization of neural tissue following a SCI [4]. In recent years, research for spinal cord neuroplasticity, the ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections, has yielded promising results for physical medicine and rehabilitation science [5-7]. Further, the integration of "coordinated neuronal activity triggered by physical activity or rehabilitative training is generally considered to be a key feature in promoting recovery following injuries to the nervous system [8]. Conversely, neural *inactivity* can lead to pruning of non-activated connections. Thus, strengthening spinal neural connectivity, through specific, coordinated, and repeated tasks, is paramount for the recovery ambulation following a SCI [4].

There have also been numerous studies that have discussed the effectiveness of locomotive training following SCI [6-10]. Locomotive training can encompass several definitions but in this report, it was used to describe any gait training technique with or without body weight support or physical assistance to achieve reciprocal stepping pattern. Currently, there are many approaches that can be utilized to facilitate gait training following a SCI: body weight support treadmill training, robotic-powered orthoses (exoskeletons), underwater gait training, and over ground training, just to list a few. A recent Cochrane Review concluded that among the various gait training techniques there is no specific method that is superior for recovery of gait following a SCI [9]. Another source reported that subjects with a history of chronic SCI (>1 year) undergoing gait training improved their walking speed and strength in 13 weeks despite any formal guidance or feedback from a trained Physical Therapist [10].

Given the variety of training options and no clear guideline for training parameters it can challenging to determine the most appropriate training method. Therefore, clinicians have a vast degree of autonomy and versatility in determining interventions options. To produce the best results, with a goal to return to a status of functional ambulation, the training needs to be task-specific and performed in repetitive massed training sessions [2]. Additionally, the interventions should be appropriate for the functional state of the individual (i.e. metabolically efficient) and should reflect the individual's goal for rehabilitation (e.g. ambulating with the least resistive assistive device) [2,3].

The individual's ultimate outcome may be affected by frequency, duration, and intensity of interventions (i.e. dose) [2]. These parameters, along with many other variables are likely to influence the repair and restoration or neurological tissues after a SCI in the acute and sub-acute setting. Further, the average length of stay following a SCI has been declining since the 1970's. The average length of stay has decreased from 24 days to 11 days and 98 days to 35 days for acute hospital and extended rehabilitation stays, respectively [1]. Given this decline, the clinician's role to efficiently optimize the frequency and intensity of interventions applied is vital to the effectiveness and outcomes of rehabilitation, but limited research is available to provide clear clinical guidelines. Thus, the purpose of this case report was to describe the application of multiple locomotive training interventions and discuss recommendations for locomotive training following a motor-incomplete SCI.

Case Description

History

A 32-year-old male presented to a sub-acute rehabilitation facility 90 days following an incomplete C5 spinal cord injury. His SCI classification was an American Spinal Injury Association

(ASIA) category C; motor-incomplete injury. Initially after the injury the patient was admitted to an intensive care unit for two weeks then remained in acute care for an additional one week. Then, he was transferred to an inpatient rehabilitation facility for approximately 9 weeks. His Physical Therapy while admitted in the in-patient rehabilitation center focused on maintaining range of motion, gaining functional mobility, working on transfer training, improving standing tolerance, managing bowel/bladder function, and using robot-assisted gait training with the Lokomat device.

In terms of function, the patient's ultimate goal was to ambulate without the use of an assistive device or the least restrictive assistive device. He also had a secondary goal of walking his sister down the aisle at her wedding with the least restrictive assistive device in 47 days from time of admission. Along with these functional goals, the patient had the desire to return to working in some capacity and be able to access the community for enjoyable leisure activities without physical restrictions.

Clinical Impression 1

Reflecting on the initial information and history collected, there were several factors that suggested this patient may be a strong candidate for locomotive training. First, the patient is young (32 years-old), which has positive influence on the tissue healing process and neural reorganization of the spinal cord (source). Second, the patient has a motor-incomplete injury (ASIA C). The success rate for restoration of walking is significantly greater for individuals in the ASIA categories of C and D compared to A (complete) and B (sensory-incomplete) [6]. Third, the chronicity of his injury is sub-acute, and he has had previous locomotive training prior to his admission to the sub-acute setting [2]. This prior experience with repetitive task-specific training may serve to prime his neural connectivity for the task of walking by activating central pattern generators. Lastly, the patient was highly motivated to return as a functional ambulator and listed his primary goal of walking again as soon as physically possible.

With these components in mind, the physical examination was designed to determine any strength or tissue length deficits, determine his general tolerance to physical activity, and rule in or out any conflicting diagnoses that would affect his ability to participate in gait training treatments. Additionally, an area of consideration was the presence of lower limb spasticity. The presence of spasticity could greatly affect the patient's ability to effectively perform specific components of the gait cycle (i.e. plantarflexion spasticity could inhibit the loading response and quality of heel strike). Lastly, the physical examination served to assess his ability to tolerate locomotive interventions. For example, it was important to determine if he could maintain an upright position (e.g. sufficient trunk strength), tolerate a sustained workload (i.e. cardiorespiratory fitness), demonstrate sufficient range of motion (ROM) for ambulation, and possess the upper extremity strength needed to assist the support of his body weight through an assistive device.

Examination

The patient exhibited normal limits of passive ROM throughout his bilateral lower extremities. The patient was also within normal limits for passive ROM for the upper extremities except his right shoulder was limited to 135 degrees of flexion secondary to shoulder pain. The patient demonstrated strength impairments consistent with his injury. He demonstrated decreased strength in both upper extremities and significant lower extremity weakness on the left side. Via manual muscle test, out of grade 5, his strength ranged from 3 to 5 on the right and 1 to 4 minus on the left for major upper and lower extremity muscle groups. Detailed strength measures are listed in *Table 1*.

The patient reported normal sensation bilaterally across all dermatome levels. As mentioned above, the presence of muscle tone or spasticity could potentially impact his performance during gait. The patient did not present with any spasticity or clonus upon initial evaluation. Also, the patient did not report any pain at rest but did experience left knee joint pain upon standing associated with hyperextension of this left lower extremity. The patient could stand for up to 30 seconds with the support of his upper extremities through a front wheeled-walker (FWW) and contact guard assist from a therapist to prevent knee hyperextension.

Regarding functional mobility and transfers, the patient could complete slide board transfers from even surfaces without physical assistance and was independent with rolling, scooting, and sitting edge of mat. He required minimal physical assistance to transition from supine to short sitting at edge of bed due to trunk and upper extremity weakness. He could sit unsupported at the edge of mat for five minutes without use of upper extremities and he was able to tolerate up to three minutes of long sitting on the mat with utilization of his upper extremities.

The patient could ambulate 50 feet using the Ekso GT with a FWW and minimum assist to maintain standing balance within the robotic gait trainer. He was unable to walk any distance upon examination without physical assistance or body weight support, but he was able to demonstrate anterior/posterior and medial/lateral weight shifting with use of upper extremities through a FWW.

Table 1. Detailed strength, functional mobility, and walking collected during initial examination.

Table 1		Left	Right
Strength	Hip flexion	2-	3+
	Knee extension	2-	4+
	Ankle dorsiflexion	1	4
	Great Toe Extension	1	4
	Ankle plantarflexion	1	4
	Elbow Flexor	4-	5
	Elbow Extensor	2	2
	Wrist Extensor	4	4+
	Finger Flexor	1	3
Range of Motion	Lower Extremity	WFL	WFL
	Upper Extremity	WFL	Limited shoulder flexion (135 degrees). All other joints WFL.
Standing	Able to stand for 30 seconds. Use of arms with FWW. Minimum assist of one to prevent knee hyperextension and trunk support for balance.		
Walking	50 feet. Ekso GT. Minimum to moderate assist of one.		
WFL= Within Functional Limits. FWW= Front wheeled-walker. Ekso GT= Exoskeleton Gait Training device. Strength measured via Manual Muscle Test out of Grade 5.			

Clinical Impression 2

Based on the data collected during the physical examination this patient remained a good candidate for locomotive training. First, he had no significant limitations in ROM that could affect his gait pattern and the examiner did not detect any significant spasticity or clonus. Second, he had active muscle contraction across all myotome levels further verifying that his injury is incomplete. In addition to having active muscle contraction across all spinal levels he also demonstrated adequate strength against gravity (>3/5 MMT) in the right lower extremity.

Further, the physical examination provided insight into his ability to tolerate standing, which is a good prognostic indicator for walking. He was also able to demonstrate fair trunk strength during sitting balance. As indicated by the strength testing results he was not able to fully extend his elbow against gravity. This could affect his ability to bear weight through an assistive device, but he did demonstrate his tolerance to standing with the use of a FWW. The amount of force from body weight supported by the patient, either through lower or upper extremities, during gait training was one variable that was continuously modified throughout the course of care.

In terms of plan of care, this patient's program focused on improving his overall strength and muscular endurance, sitting/standing balance, gait mechanics, and ambulation distance with least restrictive assistive device to maximize his independence with all functional mobility. Further, he was involved with a comprehensive strengthening and cardiovascular endurance programs throughout the week to address physical deficits and maximize overall health. The patient's performance on the objective outcomes were, for the most part, measured at the end of each week. In some instances, the outcome measures were not able to be recorded at the end of the week due to logistics with clinical equipment use, conflicting activities on the rehab campus, and other events that interfered with patient training sessions.

Interventions

Over the course of the patient's rehabilitation he participated in multiple locomotive training interventions. The interventions are listed in the order of most to least support provided: Ekso GT, Zero-G body weight suspension, Hydroworx, and over ground training. The use of each intervention was deliberately modified at different stages in the rehabilitation process to optimize gait training repetition, movement quality, and patient safety. Ultimately, the goal of implementing different locomotive interventions was to increase the volume of training specific to the task of walking. Each intervention was used in supplement to the other to achieve this goal of sustained locomotive training across several weeks.

One concern that remained throughout the rehab process was re-occurrence of knee hyper-extension during stance phase of gait. The knee hyperextension force produced significant pain and apprehension for training. Therefore, the use of a knee orthotic, as seen in *Figure 2,* was used to prevent the frequency of hyperextension moment at the knee. This allowed the patient to perform stance phase with less apprehension and ultimately increased training tolerance by removing painful gait pattern and possible knee joint inflammation. Additionally, the use of various assistive devices (e.g. FWW, platform walker, forearm crutches, etc.) were trialed to meet the demands in terms of support while providing the least amount of restriction.

Ekso GT

For this patient, the use of the Ekso GT was limited to the initial week of rehabilitation because this device is most appropriate for individuals who have limited to no motor control of their lower extremities. The Ekso GT is a powered robotic exoskeleton device that assists with force production and movement coordination required to advance lower extremities during gait. Along with decreasing the energy consumption needed for gait, the advantage of using this device is its capacity to modify assistance (either bilaterally or unilaterally) and stepping parameters. This device allows the clinician to adjust the amount of motor control required by the patient and can also assert resistance to the advancing limb to help uptrain motor patterns. This device is also capable of pre-gait activities (e.g. sit to stand and weight shifting exercises) and free-gait functions, which allows the user to ambulate without any corrective forces from device.

Figure 1. Patient participating in locomotive training with Ekso GT.

One of the most useful features of this device is the instant feedback for gait analysis (e.g. step initiation time, step height and length, lateral weight shift, and percentage of corrective force from the device) provided to the clinician via text. This feature allows the clinician to make real-time adjustments to the gait parameters to maximize the adequate stepping stimulus and streamline training time. For example, if the patient is unable to laterally translate weight during stance phase the threshold needed to initiate the next step can be changed to increase or decrease emphasis of weight shift.

While this device can be ideal for patients with little to no motor control, this device has a high physical demand due to its controlled and somewhat restrictive nature, which can limit the tolerance of training during a single session. Thus, this device had limited return for physical cost versus training volume. However, this device was useful for re-establishing mechanics of gait, improving patient affect/moral, and was used an adjunct to the other locomotive training options to improve gait mechanics (e.g. weight shift, step height, step length, etc.). This patient was able to ambulate 50 feet on the first day of training. The utilization of this device was limited to the first week of rehabilitation. At this point in the course of care other locomotive techniques were used to optimize training volume.

ZeroG Lite

In the second week, the ZeroG Lite was used for locomotion training once per day for three out of five days. It is a body weight support (BWS) tracking system that allows clinician's to precisely augment the amount of body weight experienced during gait training. The body weight settings and fall height can be customized before the beginning of a training session and also modified concurrently via wireless control. Another benefit of this device is the data being recorded during the session. The device can detect and record the amount of support the machine is providing as well as report the amount of time spent training and falls detected.

The most important feature utilized to modify the intensity for this patient was the dynamic BWS function. This allowed the clinician to increase or decrease the amount of support provided to the patient during gait training. If the patient was doing well, the clinician lowered the amount of support provided (i.e. percent body weight) and if the patient began to fatigue or quality of gait diminished then the amount of support was increased and often a rest break was given to the patient.

During the first use of this device, approximately five days after admission, the patient ambulated 500 feet with 35% BWS (45 pounds) while utilizing forearm crutches and a hip and ankle spica to facilitate hip flexion and ankle dorsiflexion, respectively. Using the ZeroG Lite, over the course of several weeks, the patient was able to increase the distance walked and decrease the amount of body weight support to10% (14 pounds), the lowest amount of BWS. Often within a session, to challenge the patient for short periods of time, the amount of body weight support was decreased to alter the intensity or demand of the task by adjusting the amount of loading forces experienced. Within some sessions the body weight support was removed entirely, assisting in progressing the patient to walk small distances with no BWS. When he was able to walk greater than 55 feet without BWS, the patient then participated in over ground locomotive training without BWS.

Figure 2. ZeroG session with hip/ankle spica wrap and knee brace.

Over Ground

Likewise, once the patient was able to demonstrate the ability to ambulate at least 55 feet without BWS then over ground (OG) training was incorporated into his weekly rehabilitation plan. By week three he was able tolerate a full session (about 30 minutes) of OG training with the assistance from a hip and ankle Spica as well as upper extremity support through a FWW. This method of training coincided with the patient goal of using the least amount of resistance for support and device. Plus, this method was a feasible training option at that point in his course of care. The interventions mentioned bove were used in adjunct with OG training with the intention of participating in as much OG training that could be tolerated by the patient.

Once the patient was able to tolerate sustained training sessions then the focus of training was aimed to refine the quality of movement. Specifically, the therapist could then focus on achieving consistent heel strike and push off sequencing at the foot and ankle. At this point in the rehab process the patient was able to efficiently engage in massed practice of gait training without the use of body weight support or assisted limb advancement through robotics. For all the locomotive interventions the parameters used at each phase of training were driven by patient tolerance which was determined by the number of steps the patient could take while maintaining safe mechanics. As the patient progressed he was able to ambulate with FWW outside of formal therapy time. Therefore, the frequency of over ground walking during his rehabilitation was difficult to accurately quantify. However, in the last few weeks he was walking outside of therapy on average of 30 minutes per day about three to five days per week.

HydroWorx

HydroWorx is an under-water treadmill system that allows clinicians to augment the amount of body weight support, speed of walking, and resistance during gait training through control of water level and water turbulence. Furthermore, this system is designed to apply resistance to the trunk and advancing limbs via internal resistance from the water while controlling the amount of body weight supported. This system can also be used for auxiliary gait training such as backwards walking, sideways walking, and pre-gait weight shifting activities.

One benefit from using this system, besides unweighting the patient, was the ability to apply progressive resistance with multidirectional water jets. This function was implemented to simulate dynamic trunk control needed during lateral gait training. Again, this technique was effective because it allowed the patient to engage in stepping patterns with decreased joint forces. Likewise, the use of HydroWorx underwater treadmill was used an adjunct method of locomotive training on days that patient was experiencing increase joint pain (i.e. left knee joint pain from repeated hyperextension) or generalized fatigue or muscle soreness. The patient participated in a total of five HydroWorx sessions with an average of 13 minutes for each session.

Additional Therapy Interventions

In addition to the locomotive interventions, the patient also completed conventional Physical Therapy to maximize strength and cardiometabolic health. This was completed five days a week for about 30-60 minutes twice per day for an average of five to ten hours a week. Conventional Physical Therapy included but was not limited to: mat mobility training, transfer and stair training, upper and lower extremity stretching and strengthening, and Functional Electrical Stimulation for upper and lower extremity cycling. On a side note, this patient actively engaged in numerous enjoyable recreational activities (kayaking, recumbent bicycling, camping, fishing etc.).

In general, moderate to vigorous aerobic and resistance training have been associated with improvements in fitness (i.e. cardiorespiratory fitness, muscular strength, and muscular power) and decreased incidence of cardiometabolic diseases (e.g. insulin-resistant Diabetes Mellitus) and bone health compromise (e.g. osteoporosis) [11]. In an effort to maximize his total health he was encouraged to participate in as much physical activity as possible. Although the conventional training listed above is not the primary focus of this report its importance for overall health and physical recovery should not be overlooked.

Outcomes

The primary outcomes assessed for this patient were the 10MWT (m/s) and the WISCI II. A secondary outcome measure used was the distance walked (m) during a training session. For the 10MWT, the patient ambulated across a 16-meter walkway with the 10-meter time collection taken in the middle. This provided three meters on either side of the testing area for acceleration and deceleration. The 10MWT was recorded using a stopwatch. The time began when any part of the patient’s body traversed the demarcated line to begin the test. The speed was then calculated by dividing distance walked by the time needed to walk ten meters. The WISCI II is an assessment index that ranks the impairment of an individual’s ability to walk after SCI. The scale ranges from a level of most severe impairment (0) to least severe impairment (20) based on the use of devices, braces and physical assistance of one or more persons.

Both the WISCI II and a quantitative timed test are used to assess functional ambulation for individuals with SCI. The International Campaign for Cures of Spinal Cord Injury Paralysis (ICCP) recommends the specific use of the 10MWT and the use of a quantitative timed-test to asses functional ambulation. This recommendation is also supported by an expert committee assembled by National Institute on Disability and Rehabilitation Research (NIDRR), whom concluded that the 10MWT and WISCI II provide the most valid measure of improvement in ambulation for individuals with SCI [12].

Both the 10MWT and WISCI II have high test-retest reliability (0.983 and 0.994, respectively) and interrater reliability (0.974 and 1.0, respectively) [8, 13]. The validity for the 10MWT is considered excellent when correlated with the TUG in the acute stage (2 weeks, r= 0.89) of SCI but decreases with increased time since injury (i.e. 12 months, r= 0.78). The validity for the WISCI II is excellent (r= 0.60 to 0.74) when correlated with the TUG, 10MWT, and 6MWT for walking ability. However, the validity of this test decreases (r= 0.16 to 0.24) for subjects who are considered dependent ambulators (i.e. WISCI II level 0 to 10).

In total, this patient participated in 13 weeks of both locomotive training and convention Physical Therapy. During this time the patient improved his 10MWT from 0.22 m/s to 0.31 m/s (41.1 % change). The MCID for the 10MWT is 0.13 m/s, thus this patient’s improvement was not clinically meaningful [13]. The patient’s severity of impairment on the WISCI II scale improved from level 6 to level 12 (100 % change). The MCID for the WISC II is 0.785, thus a change of 1 level is considered clinically significant [12]. Additionally, the patient was able to demonstrate an increase in walking distance from 50 feet using the Ekso GT to 1000 feet with FWW and stand by assistance.

Discussion

The purpose of this case report was to describe the feasibility and considerations for application of locomotor training following incomplete SCI using various intervention methods. As mentioned above, the goal of rehabilitation for an individual with SCI is to facilitate the mechanisms responsible for re-acquisition of a motor skill through activity-dependent massed practice. To achieve this goal several approaches were used to maximize the dose and energy efficiency as well as maintaining patient safety. At several stages in the rehabilitation process, different gait training techniques were again utilized to maintain adequate and frequent external stimulus aimed towards actively re-organizing the spinal cord.

According to the data collected, the patient demonstrated clinically significant changes for WISCI II score. However, did not demonstrate a meaningful change in functional walking speed. Despite not achieving a clinically significant gain in walking speed this patient was able to decrease the amount of assistance during ambulation from practically dependent to modified independent. One limitation noted is the different mode of assistance used for each measurement, which may have affected the collected data (i.e. Ekso GT at baseline and then OG at conclusion). Considering the patient was not able to ambulate without dependent assistance upon admission this change in function may have be significant to the patient even though it was not indicated by the results. Therefore, for clinician’s, there should be a focus on both the functional ability and the quality of movement.

Another area to consider is the current discrepancy between activity guidelines for individuals with SCI compared to general population activity guidelines. For healthy adults (18-64 years old) the World Health Organization recommends at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity physical activity per week with two or more days involving resistance training of major muscle groups [14]. On the other hand, for individuals with SCI the activity recommendations are 40 minutes of aerobic activity and 40 minutes of resistance training per week with at least two bouts to meet both recommended minutes. On average, individuals with SCI participate in less exercise compared to the other disability groups and the general population [10]. Given the high propensity of accumulating deleterious affects from deconditioning (e.g. bone density loss, cardiovascular deconditioning, etc.) the need for physical activity and exercise is paramount to the health of an individual who has undergone spinal cord damage. However, at this time, more data is needed to design the appropriate activity guidelines for individuals with SCI to maximize health benefits.

In summary, this report was able to demonstrate the utilization of locomotive training to optimize recovery of ambulation in a patient following an incomplete SCI. Like other case reports conducted in this area of study this report highlights several possible gait training options for individuals with SCI. Again, it cannot be assumed that the improvements made during Physical Therapy are due to intervention choice or dose; therefore, conclusions can’t be concluded from a single case report. There is currently not enough data to synthesize prescription guidelines for gait training, or exercise for that matter, for individuals with SCI. In other words, the dose that yields the most optimal results for gait training has yet to be determined. Thus, to decrease the knowledge gap, more large-scale data collection is necessary to determine the training dosages for individuals with SCI.

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