Walking Following Spinal Cord Injury

What Lower Limb and Walking problems occur after Spinal Cord Injury?

- Loss of function in the lower limbs due to SCI can extend from complete paralysis to varying levels of voluntary muscle activation. The research on rehabilitation of lower limb function after SCI has generally focused on the recovery of walking.
- Even when functional ambulation may not be possible (e.g., in complete tetraplegia), lower limb interventions can be targeted to maintain muscle health as well as reduce other complications, such as decreased cardiovascular health, osteoporosis, or wounds. Minimizing the risk of these complications would ease health costs related to the treatment of these sequelae and also could promote participation in society and/or the workforce.

What are the chances of recovering the ability to walk after Spinal Cord Injury?

- Most patients classified with an AIS A (complete motor and sensory) spinal cord injury have lower likelihood of walking independently in the community compared to the other AIS grading levels (Scivoletto et al. 2014). People first classified as AIS A who regain some community walking function usually have lower levels of injuries (T12-L3) and change classification (i.e., improve) over the course of rehabilitation (Scivoletto et al. 2014).
- Overall ambulation recovery for people with AIS B injuries (motor complete, sensory incomplete) is approximately 33% (Scivoletto et al. 2014).
- People with AIS C and AIS D injuries generally have a good prognosis for regaining some ambulation or standing function (Scivoletto et al. 2014). This will depend on the level of injury, as well as pain and spasticity issues that may limit mobility.
- There has been some research done on predicting who will or will not be able to walk after SCI, looking at factors like age, injury level and severity, and voluntary movement or strength in certain muscle groups. Hicks et al. (2017) (https://www.ambulation.ca/) state that walking ability can be predicted with relatively high accuracy with 3 variables: age, L3 motor score at admission, and S1 light touch sensory score at admission. Generally speaking, those with lower levels of injuries or incomplete SCI (i.e., the spinal cord is not completely severed) will be more likely to walk post-SCI.

What management options are there for lower limb and walking following Spinal Cord Injury?

Overground Training

- Overground training is most feasible in individuals with higher function (i.e., motor incomplete SCI). Overground training provides an important mode of exercise for improving walking function, and likely other physical and mental functions (e.g., muscle strength, bone health, cardiovascular function, depression symptoms) shown to be positively affected by exercise in the general population. Different overground training approaches (e.g., progressively challenging locomotor training [LT] over variable surfaces, motor skills training [MST], and intradural/intramedullary surgical intervention combined with long-term weight-bearing LT) may result in long-lasting benefits in patients with SCI (Lotter et al. 2020; Brazg et al. 2017; Amatachaya et al. 2021; Evans & Field-Fote 2024; Liu et al. 2021; Oh & Park 2013).
- Mobility improvements of overground and treadmill-based training are comparable in patients with SCI (Senthilvelkumar et al. 2015). One RCT showed that high-intensity (70%-85% HR_{max}) LT provides significantly greater improvements in selected walking variables (peak treadmill speed and fastest-possible speeds) compared to low-intensity (50%-65% HR_{max}) LT in participants with chronic and motor incomplete SCI (Brazg et al. 2017).

Body-Weight Supported Treadmill Training (BWSTT)

- There is evidence from multiple RCTs and pre-post-studies that body weight-support gait training can improve walking outcomes in people with acute or chronic SCI, but most body weight-support strategies (overground, treadmill [body-weight supported treadmill training, BWSTT], with functional electrical stimulation [FES], with the hybrid assistive limb [HAL] exoskeleton) are equally effective at improving walking function (walking speed, walking distance and/or walking ability) and/or lower extremity muscle strength (Alcobendas-Maestro et al. 2012; Yildirim et al. 2019; Sadeghi et al. 2015; Dobkin et al. 2006; Hornby et al. 2005a; Çinar et al. 2020; Field-Fote & Roach 2011; Alexeeva et al. 2011; Piira et al. 2019a; Piira et al. 2019b).
- There is one RCT which showed that intensive sessions (walking time per session > 50 min) of Lokomat-assisted BWSTT for 8 weeks could provide more improvement in functional walking than non-intensive sessions (walking time per session < 25 min) in patients with acute SCI; so, longer durations of BWSTT sessions are encouraged when possible (Wirz et al. 2017).

Orthoses/Braces

- Many people with SCI use orthoses/braces to improve lower limb stability or deal with problems like drop-foot, even though there is limited research supporting their use.
- It has been suggested that orthoses or braces are best for people with complete SCI at T9 or below or incomplete SCI at any level, with good postural control and good level of fitness (Franceschini et al. 1997; Thoumie et al. 1995; Hong et al. 1990).
- Two studies examined the immediate effects of an ankle-foot orthosis (AFO) after randomizing different brace conditions (Kim et al. 2004; Arazpour et al. 2013). Positive effects consisted of increased gait speed, step length, cadence and improved performance on the 6MWT. It is generally recognized in the field that effects from an AFO are attained immediately, although it is likely that practice over a few sessions may improve a participant's confidence, learning and function. It is also possible that people with orthoses, or those using walkers, elbow crutches, or other assistive aids, may not achieve walking speeds that are safe for community ambulation (Senthilvelkumar et al. 2023).

Wearable Powered Exoskeletons (WPE)

- Wearable powered exoskeletons (WPEs) are computer-guided systems using motorized orthoses that are donned by people with disabilities to assist with voluntary and involuntary movement (Rodriguez-Tapia et al. 2022; Jamwal et al. 2022).
- Newer generations of exoskeletons have been designed with increased mobility and portability (Yip et al. 2022). These devices, known as overground exoskeletons, are designed with portable systems that allow the user to ambulate freely indoors and outdoors, and have provided clinicians and patients with SCI a useful tool to increase overground walking capacity (Yip et al. 2022).
- There is evidence from multiple RCTs and other lower-quality studies that wearable exoskeleton-assisted gait training enables safe walking and provides improvements in gait and strength outcomes in patients with SCI at different levels of injury, AIS classification, or time since injury (Rodríguez-Fernández et al. 2022; Edwards et al. 2022; Xiang et al. 2021; Gil-Agudo et al. 2023; Tsai et al. 2024).
- There is insufficient evidence that wearable exoskeleton-assisted training provides better walking function, or energy expenditure outcomes compared with other approaches (such as robotic-assisted gait training [RAGT] with Lokomat or KAFOs) in patients with SCI (Rodríguez-Fernández et al. 2022; Edwards et al. 2022; Xiang et al. 2021; Gil-Agudo et al. 2023).

Neuromodulation

Neuroplasticity refers to the capacity of the nervous system to modify its structural and functional organization, adjusting itself to changing demands and environment; neuromodulation can be defined as the induction of neuroplastic changes via local application of electrical, magnetic, acoustic, optic, tactile, or pharmacological stimuli (De

Ridder et al. 2016). The SCIRE YouTube channel demonstrates neuromodulation a number of ways, including chemically (intrathecal baclofen), via electrical stimuli (FES and epidural stimulation), and magnetic fields (transcranial magnetic stimulation [TMS]).

Neuromodulation can be applied to three main areas of the body: the brain, the spinal cord, and the peripheral nerves, through invasive and/or non-invasive approaches.

In recent years, the combination of walking or strength training with neuromodulation of the brain or the spinal cord has been investigated as a means to enhance the excitability of motor circuits and to increase training efficacy, promoting motor recovery (Hofer & Schwab 2019).

Functional Electrical Stimulation (FES) to Enhance Walking Function:

- Functional Electrical Stimulation (FES) - electrical stimulation is applied to peripheral muscles and the nerves located outside the spinal cord and brain. This stimulation causes the muscles to contract and can assist with purposeful or functional movement in weak or paralyzed muscles. FES is delivered using a variety of handheld or specialized commercial electrical therapy machines connected to electrodes that are placed on the skin's surface.
- Studies in SCI typically show that FES paired with exercise or walking training leads to better improvements in walking or strength than the exercise alone. This is often because a muscle is activated by the stimulation that normally cannot be voluntarily activated by the person with SCI.
- Of greater interest is carryover effects found after FES training. Several investigators have reported that improvements in walking have (e.g., overground walking speed and distance, step length) been present even when the stimulator was turned off, suggesting that neuroplastic changes have taken place in response to regular use of FES and walking training (Ladouceur & Barbeau 2000b; Wieler et al. 1999).

Transcranial Direct Current Stimulation (tDCS) and Repetitive Transcranial Magnetic Stimulation (rTMS):

- Other types of transcutaneous stimulation, like repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) attempt to stimulate the brain and the spinal cord non-invasively (i.e., from outside of the body).
- There are multiple RCTs showing that the concurrent application of transcranial direct current stimulation (tDCS) does not seem to further enhance the effects on walking and strength outcomes of MST (Evans et al. 2022; Evans & Field-Fote 2022), overground gait training (OGT) (Klamruen et al. 2024), or BWSTT (Kumru et al. 2016b; Simis et al. 2021; Raithatha et al. 2016) in patients with motor-incomplete SCI.
- According to multiple RCTs, locomotor or exercise training combined with rTMS do not provide more benefits in walking function compared with exercise alone (Krogh et al. 2021; Kumru et al. 2016a; Nogueira et al. 2024).

Spinal Cord Stimulation Combined With Locomotor Training (LT):

- Different neuromodulation approaches to stimulate the spinal cord have been used, including transcutaneous, which is a non-invasive method, and epidurally and laparoscopically, which are invasive methods requiring surgery.
- According to different RCTs and one prospective controlled trial, concurrent application of transcutaneous spinal current stimulation (tSCS) seems to enhance the effects on walking and strength outcomes of LT (BWSTT or overground) or sit-to-stand and standing training in patients with chronic SCI (Estes et al. 2021; Hawkins et al. 2022; Al'joboori et al. 2020).
- Several pre-post studies have been published generally showing that epidural spinal cord stimulation (ESCS) is a safe procedure, and combined with a subsequent LT has promising effects on the recovery and improvements in walking capacity, LEMS, and independence in ADLs in patients with chronic and complete or severe motor paralysis (Kathe et al. 2022; Rowald et al. 2022; Wagner et al. 2018). A few studies examining laparoscopic implantation of neuroprosthesis (LION) in the pelvic lumbosacral nerves (i.e., sciatic, pudendal, and femoral nerves) show that it is a safe surgical approach, and followed by an intensive rehabilitation protocol, it can provide long-term beneficial effects on walking ability in patients with chronic and complete SCI (Kasch et al. 2021; Lemos et al. 2023; Possover 2021).
- It should be noted that epidural spinal cord implantation has yet to be approved in many countries, including Canada and the USA. LION is approved only in certain circumstances and using only certain protocols for people with SCI.

Biofeedback and Virtual Reality

Biofeedback is a process where instruments measure physiological activity and 'feed back' information to the user, as in electromyography, mirror therapy, or force sensors.

Virtual Reality (VR) is a computer-based technology that allows users to interact in a computer-generated environment, allowing the practice of rehabilitation exercises in a safe and controlled environment; it can be low-tech and semi-immersive (e.g., video game consoles with cameras) or high-tech and fully immersive (e.g., VR goggles, VR caves).

Because people with SCI lack sensation/sensory input below their level of injury, biofeedback and VR can compensate and provide visual feedback on body position or cue stepping and standing, to assist and enhance movement practice, as well as increasing adherence to rehabilitation and facilitating home-based or telerehabilitation.

- Several studies have been conducted including people with chronic SCI, who performed standing and walking programs coupled with virtual reality (VR) or biofeedback with promising results that VR/biofeedback enhances walking more than walking training alone (An & Park 2018, 2022; Donati et al. 2016; van Dijsseldonk et al. 2018; Villiger et al. 2017; Zwijgers et al. 2024; Amatachaya et al. 2023).