# Sitting and Standing Balance Following Spinal Cord Injury

## Balance Definition and Components

Balance, defined as the ability to maintain or recover the centre of mass within the base of support; is important for activities of daily living, general mobility, and prevention of falls (Maki & McIlroy 2006). Physiologically, balance is not a singular ability, but rather the ability of various systems to work together. The Systems Framework of Postural Control, first described by Horak (2006), is a comprehensive approach describing the components of balance to guide assessment and treatment. The 10 components of balance include:

1) Functional stability limits,
2) underlying motor systems,
3) static stability,
4) verticality,
5) reactive postural control,
6) anticipatory postural control,
7) dynamic stability,
8) sensory integration,
9) cognitive influences,
10) balance confidence.

Musselman et al. (2022) reported that all 10 components of balance are impaired to varying degrees in people with SCI. Functional stability limits, underlying motor systems, sensory integration, static stability, reactive postural control, cognitive influences, and balance confidence are all impacted more greatly by SCI, while the effect on verticality is minimal. The severity of impact for some components, like dynamic stability and anticipatory postural control is variable and likely depends on the severity of injury. When assessing balance, it is important for healthcare professionals to consider all 10 components, as impairments in any one of them can impact overall performance. To optimize treatment, interventions should then be tailored to each individual's needs based on which components are most greatly impacted.

## Measuring Balance

Assessment of balance function in clinical settings can be performed using biomechanical instruments or clinical assessment tools (Arsh et al. 2021). Many research studies will use instrumented assessments like inertial measurement units, force plates, or motion capture systems, allowing for greater sensitivity in balance assessment; however, they are often costly and not widely available in clinical settings (Arora et al. 2020; Musselman et al. 2022). Until more accessible and affordable options become available, it is best for clinicians to focus on using validated clinical outcome measures (Arora et al. 2020).

Arsh et al. (2021) systematically reviewed articles reporting the validity and reliability of diagnostic tests used to assess balance function in patients with SCI. The following 10 clinical instruments were reported: Functional Reach Test (FRT), Berg Balance Scale (BBS), Mini-

Balance Evaluation Systems Test (Mini-BESTest), Function in Sitting Test (FIST), T-Shirt Test, Motor Assessment Scale item 3, Sitting Balance Score, Five Times Sit to Stand Test (FTSTS), Tinetti scale, and Sitting Balance Measure. The Timed Up and Go (TUG) Test was included as a balance measure in Hosseinzadeh et al. (2024), who aimed to test the psychometric properties (reliability and validity) of outcome measures used to assess walking and balance in people with SCI.

## Sitting Balance

Sitting balance is a significant component of independent daily living for people with SCI, especially those with cervical level injuries or those with complete injuries at the thoracic/lumbar level (Lei et al. 2023). It is especially important to consider sitting balance in people with SCI as they may have limited trunk control, and an otherwise simple daily task, like reaching for something, moves the person's center of gravity, and they may lose their balance putting them at risk for falls. Dressing, wheelchair handling, transfers, sitting on the edge of or across surfaces, and toileting all require a combination of static and dynamic postural control involving the trunk (Lee & Lee 2021; Tak et al. 2015). Therefore, the rehabilitation of sitting balance is beneficial for enhancing quality of life after SCI.

It has been shown in individuals with motor-complete thoracic SCI that dressing or reaching while sitting with reduced thigh support provides more challenges in the dynamic sitting balance (postural control measured by the center of pressure parameters) than sitting with more thigh support (Ilha et al. 2020). Also, it has been shown that participants with cervical SCI are more reliant on visual and vestibular systems for sitting balance while depending less on proprioception and muscle control compared to controls (because they may not have control on these functions to maintain balance); showing that this strategy is ineffective in maintaining postural stability during unsupported sitting (Lei et al. 2023). Consequently, emphasizing the importance of proprioception and muscle control for seated postural stability and/or training during unsupported sitting to improve sitting balance is important in people with upper SCI (Ilha et al. 2020; Lei et al. 2023).

### What Management Options are There for Sitting Balance Following Spinal Cord Injury (SCI)?

- Virtual reality (VR):

In recent years, technological advances such as VR have been introduced in the field of SCI rehabilitation and are being used as a therapeutic tool (Abou et al. 2020). The addition of VR to different seated exercise interventions provides significant improvements in sitting balance function for people with SCI compared with real world-task specific balance or standard rehabilitation (Abou et al. 2020; Wang et al. 2024).

- Exercise and Activity-Based Therapy (ABT):

Exercise interventions that have been tested on balance in people with SCI include: wheelchair skills training programs, therapeutic exercise in unsupported sitting, seated/wheelchair Tai Chi, arm crank ergometry, kayak ergometry, Spinal Mobility, and ABT.

RCTs in sitting balance for people with SCI were shown for wheelchair skills training programs and for seated Tai Chi programs, when compared to conventional physical therapy

(Nam et al. 2023; Qi et al. 2018). Other studies of lower quality also showed positive results on sitting balance for arm crank ergometry, a Spinal Mobility program (comprising resistance exercises, aerobic conditioning, trunk stability and health education), and ABT (Williams et al. 2020; Sliwinski et al. 2020; de Oliveira et al. 2023; de Oliveira et al. 2019; Larson 2022).

One RCT on task-specific sitting balance showed no difference between it and standard rehabilitation, though it is likely that the 6-week training program was too short to show treatment effects (Harvey et al. 2011).

- Body-weight supported locomotor training (BWSLT):

The main aim of BWSLT is the improvement of walking and/or standing balance functions, but some studies included sitting balance as a secondary outcome.

Results are generally mixed or insignificant; some smaller studies showed that BWSLT report positive effects in sitting balance and/or trunk muscle strength, but RCTs in this area show no differences between BWSLT and standard rehabilitation (Khan et al. 2019b; Tsai et al. 2021; Okawara et al. 2020; Okawara et al. 2022; Piira et al. 2019a; Piira et al. 2019b; Martinez et al. 2018).

- Electrical Stimulation:

Though not yet definitive, it seems that different electrical stimulation approaches (e.g., electromyography triggered electrical stimulation [EMG-ES] and functional electrical stimulation [FES]), paired with an exercise program especially focusing on trunk muscles, are beneficial in improving sitting balance function in people with complete and/or incomplete SCI. (Bayraktar et al. 2024; Bergmann et al. 2019).

## Standing Balance

Up to 75% of individuals with incomplete SCI experience falls while standing and frequent losses of balance post-rehabilitation (Arora et al. 2020; Brotherton et al. 2007). Moreover, falls are among the most common causes of SCI in persons > 60 years old (Dohle & Reding 2011).

### What Management Options are There for Standing Balance Following Spinal Cord Injury (SCI)?

- VR:

In participants with chronic SCI, VR (including electromyography [EMG] biofeedback or visuotemporal cues) provides higher benefits in standing balance than usual care or interventions without the VR/biofeedback addition (An & Park 2022; Amatachaya et al. 2023; Nithiatthawanon et al. 2020; Pramodhyakul et al. 2016).

Participants with acute SCI have been less studied than those with chronic SCI, and the only study of high quality has shown no differences between VR training and conventional therapy (Sengupta et al. 2020).

- Non-Body-Weight Supported Training:

Overground walking training has the advantages of being inexpensive, more closely resembling daily life, and likely to achieve a patient's full engagement, encouraging voluntary movements compared to walking on a treadmill (Yu et al. 2019).

High-quality studies have found significant improvements in standing balance in people with SCI by using intensive balance training/perturbation-based balance training (Unger et al. 2021), task-specific stepping practice (Lotter et al. 2020), walking training program on a track with different surfaces (Amatachaya et al. 2021), rebound therapy (Sadeghi et al. 2019), and lower limb resistance training programs at maximum intensity (Jayaraman et al. 2013).

On the other hand, an RCT assessing 24 weeks of ABT did not provide significant improvements in standing balance in comparison with a control intervention (Jones et al. 2014a).

One high-quality study found no differences in standing balance improvements when comparing high-intensity (70%-85% $HR_{max}$) locomotor training to low-intensity (50%-65% $HR_{max}$) locomotor training (Brazg et al. 2017).

- Body-weight supported treadmill training (BWSTT):

BWSTT is the intervention more extensively studied in participants with SCI for improving standing balance function; we found 38 studies with a total sample size of 1815 participants.

High-quality studies on participants with acute SCI have shown that BWSTT has similar effects to conventional rehabilitation, consisting of an equivalent amount of overground mobility practice for standing balance (Dobkin et al. 2006; Midik et al. 2020; Shin et al. 2014). For participants with chronic SCI, the higher quality studies have also shown that different BWSTT approaches (e.g., robotic-assisted gait training [RAGT] with Lokomat, BWSLT with manual assistance, or BWSTT with assistance using a cable-driven robotic device) provide similar improvements in standing balance function than other non-body-weight supported training (e.g., usual care, overground 'precision' skilled walking training, strength training, or BWSTT with no assistance) (Labruyere & van Hedel 2014; Piira et al. 2019a; Piira et al. 2019b; Yang et al. 2014; Wu et al. 2018).

Because of the limited motor control and balance functioning recruited, BWSTT is likely not the ideal approach for improving standing balance in people with SCI.

- Wearable exoskeletons:

The number of studies on wearable exoskeletons during the past 10 years has seen a rapid increase; we found 17 studies including 270 participants with SCI assessing the training effect of wearable exoskeletons on standing balance.

Studies of high quality show that wearable exoskeleton-assisted training does not provide higher improvements in standing balance compared with other interventions (such as BWSTT or training regimens using knee ankle foot orthoses [KAFOs]) (Edwards et al. 2022; Rodríguez-Fernández et al. 2022; Chang et al. 2018).

These results, plus the fact of high heterogeneity in training dosage or models in exoskeletons, the numerous adverse events (AEs) reported, or high cost, among others, should be taken into account when providing research-clinical recommendations.

- Neuromodulation:

- FES: Five studies, including 178 participants with chronic SCI, show that FES-cycling and FES-assisted BWSTT do not provide greater benefits in standing balance versus the same interventions without FES (Galea et al. 2018; Kapadia et al. 2014).

- Transcranial direct current stimulation (tDCS): Four studies, including 118 participants with chronic SCI, show that the addition of tDCS to different exercise interventions (e.g., gait retraining, motor skill training) provides no differences in standing balance when compared to the same exercise interventions paired with sham stimulation. (Simis et al. 2021; Raithatha et al. 2016; Evans et al. 2022; Klamruen et al. 2024).

- Repetitive transcranial magnetic stimulation (rTMS): Three studies, including 77 participants with acute/subacute motor incomplete SCI, found that rTMS before exercise training does not provide additional improvements when compared to exercise training plus sham stimulation (Krogh et al. 2021; Benito et al. 2012; Naro et al. 2022).

## Gaps in the Literature

- Many studies we found tested balance as a secondary outcome with walking as the primary outcome; specifically studying balance function as a primary outcome in SCI should improve data available, and in turn, clinical recommendations.
- Most studies we found testing balance in SCI, even high-quality RCTs, have fewer than 20 people per condition; authors of recent systematic reviews have stated that more well-designed and appropriately powered RCTs testing balance function are needed (Benn et al. 2025; Walia et al. 2023).
- Most studies on balance in people with SCI include people with incomplete injuries and at the chronic phase of SCI; more studies including people at the acute phase of injury and/or complete SCI would provide results more representative of the general SCI population.