Review

Current state of balance assessment during transferring, sitting, standing and walking activities for the spinal cord injured population: A systematic review

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Context: Comprehensive balance measures with high clinical utility and sound psychometric properties are needed to inform the rehabilitation of individuals with spinal cord injury (SCI).

Objective: To identify the balance measures used in the SCI population, and to evaluate their clinical utility, psychometric properties and comprehensiveness.

Methods: Medline, PubMed, Embase, Scopus, Web of Science, and the Allied and Complementary Medicine Database were searched from the earliest record to October 19/16. Two researchers independently screened abstracts for articles including a balance measure and adults with SCI. Extracted data included participant characteristics and descriptions of balance measures. Quality was evaluated by considering study design, sampling method and adequacy of description of research participants. Clinical utility of all balance measures was evaluated. Comprehensiveness was evaluated using the modified Systems Framework for Postural Control.

Results: 2820 abstracts were returned and 127 articles included. Thirty-one balance measures were identified; 11 evaluated a biomechanical construct and 20 were balance scales. All balance scales had high clinical utility. The Berg Balance Scale and Functional Reach Test were valid and reliable, while the mini-BESTest was the most comprehensive.

Conclusion: No single measure had high clinical utility, strong psychometric properties and comprehensiveness. The mini-BESTest and/or Activity-based Balance Level Evaluation may fill this gap with further testing of their psychometric properties.

Keywords: Spinal cord injuries, Postural balance, Outcomes assessment

Abbreviations

SCI	spinal cord injury
BOS	base of support
COM	center of mass
EMG	electromyography
COP	center of pressure
BBS	Berg Balance Scale

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
AIS	American Spinal Injury Association Impairment Scale
FRT	Functional Reach Test
DGI	Dynamic Gait Index
mini-BESTest	mini-Balance Evaluation Systems Test
ABLE	Activity-Based Balance Level Evaluation
CB&M	Community Balance & Mobility Scale

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Introduction

Over 280,000 Americans are living with a spinal cord injury (SCI).¹ The injury can cause sensorimotor deficits

that frequently manifest as impaired balance, which in turn can lead to falls. A high occurrence of falls has been reported among individuals with SCI, with 34% to 75% of the studied samples reporting at least one fall.^{2–10} Wheelchair-users typically fall during transfers,¹¹ whereas ambulatory individuals fall while performing an upright activity like walking.⁵ Falls can lead to injuries,⁹ costly hospital admissions,¹² a fear of falling, and subsequent restriction in community participation.¹³ While falls may result from a variety of extrinsic (e.g. environmental hazards) and intrinsic (e.g. reduced strength and sensation) factors, impaired balance control is likely experienced by the majority of individuals with SCI who fall.^{2,7,13}

Balance or postural control involves maintaining, achieving, or restoring a state of stability during any posture or activity.¹⁴ Effective balance control is essential for avoiding falls and is dependent on the integration of various sensory inputs, and the interaction of the body with the changing environment.¹⁵ A modified version of the Systems Framework for Postural Control^{15,16} identifies nine major components for the maintenance of balance – 1) functional stability limits (e.g. size of base of support (BOS)¹⁷), 2) underlying motor systems (e.g. muscle strength), 3) static stability (e.g. maintaining center of mass (COM) within BOS¹⁷), 4) verticality (e.g. orienting the body parts relative to gravity, the support surface, visual surround, and internal references¹⁸), 5) reactive postural control (e.g. hip or ankle movement to regain body equilibrium after balance is perturbed¹⁹), 6) anticipatory postural control (e.g. modulation of lower extremity muscle activity in anticipation of a perturbation¹⁹), 7) dynamic stability (e.g. maintaining body equilibrium in situations when the BOS is changing²⁰), 8) sensory integration (e.g. re-weighting the contributions of somatosensory, visual and vestibular inputs depending on the context and sensory capabilities of the individual^{17,21}), and 9) cognitive influences (e.g. how attentional resources are allocated to maintain balance while performing a task²²). The postural strategies selected by individuals are context-specific and depend on functional abilities, environmental conditions, and the task demands.¹⁶ Acknowledging the different components of postural control is important for the assessment of balance, the identification of individuals at increased risk of falls, the design of effective fall prevention programs, and the monitoring of changes in balance control over time. A comprehensive balance assessment measure should capture all components of balance.¹⁶

Compared with older adults and other neurological populations,^{23–25} there is a paucity of information regarding what measures of balance are available and

appropriate for the SCI population.²⁶ The SCI EDGE Task Force recently published recommendations concerning outcome measurement in SCI rehabilitation practice and teaching.²⁶ Through a consensus-based approach and non-systematic literature searching, the Task Force identified seven measures of balance for the SCI population with one, the Berg Balance Scale (BBS), receiving ‘recommended’ ratings.²⁶ The recommendation was based on the clinical utility and psychometric properties of the outcome measures, but did not consider comprehensiveness; an important consideration for any measure of balance. Further, given that >50 measures have been validated for the assessment of standing balance in clinical environments in adult populations,¹⁵ it is likely that a greater number of balance measures have been used with the SCI population, and would be identified through systematic searching.

In order to provide guidance to clinicians and researchers regarding what balance measures are comprehensive, psychometrically-sound and clinically feasible for individuals with SCI, we completed a systematic review. The objectives were threefold: 1) identify what balance control measures have been used to assess balance during transfers, sitting, standing, and walking in individuals with SCI; 2) evaluate the comprehensiveness (i.e. extent to which measures are inclusive of the components of the Systems Framework for Postural Control) and psychometric properties of the identified measures; and 3) provide recommendations for the assessment of balance control in individuals with SCI in clinical settings.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used to conduct a systematic review.²⁷ There is no registered protocol for this review. A research question was formulated systematically by using a modified patient population, intervention or indicator, comparator, outcome, and study design (PICO) framework.²⁸ The population was adults with SCI. The indicator was any measure of balance during sitting, standing, walking, or transferring. There was no comparator. The outcome was balance control or ability to maintain balance. There were no restrictions on the study design with the exception of systematic reviews and meta-analyses.

Search strategy

Medline, PubMed, Embase, Scopus, Web of Science, and the Allied and Complementary Medicine Database were searched from the earliest record to October 19, 2016 ([Appendix](#)) using keywords and

controlled vocabulary (as appropriate). Articles were not restricted on the basis of language, date, or type of publication. The reference lists of the articles that were included were screened to identify any relevant studies not returned in the systematic search of the databases.

Abstracts were de-duplicated using a research management tool (RefWorks-COS), and then reviewed independently by two researchers to identify those to be included for full-text screening. The inclusion criteria for full-text screening were as follows: (a) article included a measure of balance, and (b) article included participants with a SCI that were rated an A, B, C or D on the American Spinal Injury Association Impairment Scale (AIS). The acute, sub-acute and chronic stages of SCI were included, as were traumatic and non-traumatic causes of SCI. The exclusion criteria for full-text screening were as follows: (a) article included a measure of mobility, and not balance per se (such as the 10-Meter Walk Test, 6-Minute Walk Test, Timed Up-and-Go),²⁹ (b) article included a measure of a psychological construct of balance (i.e. balance

confidence or self-efficacy, fear of or concern about falls), and not a measure of balance ability, (c) conference abstracts, (d) review articles not presenting original data, and (e) animal studies. In the case of a disagreement regarding inclusion, a third researcher reviewed the abstract to make a final decision. Screening of full-texts for inclusion was divided between all four researchers, with one researcher (TA) reviewing all full-texts to ensure consistency. The same inclusion and exclusion criteria used for the abstract screening were used for the screening of full-texts.

Data extraction

Data from included full-text articles were entered into a data extraction table. Extracted data included information on participant characteristics, study design, and descriptions of the balance measures used including psychometric properties (explicitly tested validity, reliability and responsiveness). In the case of full-texts written in a language other than English, individuals proficient in that language assisted with data extraction.

Methodological quality was evaluated by adapting the methods of Bisaro *et al.*³⁰ and Dobson *et al.*³¹ Articles were evaluated on the adequacy of the description of the following: research participants, inclusion/exclusion criteria, sampling methods, method of data collection (i.e. prospective/retrospective), and psychometric properties of the balance measures used in the study. These categories were rated as adequate/partial, stated/not stated or yes/no, depending on the question (see Table 1 for operational definitions of ratings). Methodological quality was evaluated independently by two researchers during data extraction. If the researchers disagreed on a rating, the final data entry was agreed upon through discussion.

Data synthesis

The extracted data were synthesized to describe the use of balance measures in individuals with SCI. First, the total number of studies in which each measure was used was counted to identify the most frequently used measures. As the number and variety of measures directly assessing a biomechanical construct were large, these measures were grouped into the following categories to facilitate description: (a) measures related to center of pressure (COP) or COM, (b) electromyography (EMG), (c) forces or torques, (d) joint angles using motion capture, (e) instrumented reaching distance, (f) instrumented gait variables (e.g. foot placement variability), (g) reaction time or movement time, (h) others including fall threshold based on peak velocity and size of excursion, damping factor, and linear

Table 1 Study quality evaluation tool (Adapted from Bisaro *et al.*³⁰ and Dobson *et al.*³¹).

Question	Decision Rules
Are participants characteristics adequately defined, including age, sex, level of injury, AIS level, time since injury?	<ul style="list-style-type: none"> – Adequate = all details – Partial = 1 or 2 missing – Inadequate = more than 2 missing
Are inclusion/exclusion criteria stated?	<ul style="list-style-type: none"> – Stated = Clear list of both – Limited = 1 or 2 points only – Not Stated = no details of either
What was the sampling method used?	<ul style="list-style-type: none"> – Convenience* – Community-based† – Population-based‡ – Not stated
Was the balance assessment performed prospectively or retrospectively?	<ul style="list-style-type: none"> – Prospective = balance assessed at the time of study – Retrospective = balance assessed before beginning of the study, e.g. chart review
Was the reliability of the measure stated or demonstrated?	<ul style="list-style-type: none"> – Yes (list type[s], e.g. inter-rater, test-retest, internal consistency) – No
Was the validity of the measure stated or demonstrated?	<ul style="list-style-type: none"> – Yes (list type[s], e.g. concurrent, criterion, and content) – No
Was the responsiveness of the measure stated or demonstrated?	<ul style="list-style-type: none"> – Yes – No

*Participants included patients from the local hospital.

†Participants recruited from ≥ 1 local hospital or organization with the aim of reaching all potential participants in the area.

‡As per community-based, but geographical area larger (e.g. country- or state/province-wide).

AIS, American Spinal Injury Association Impairment Scale.

momentum. Next, the task(s) performed during each balance measure/grouping was identified to provide further description. Categories of tasks included sitting (e.g. supported/unsupported quiet sitting, reaching), standing (e.g. with eyes opened/closed, on stable/unstable surfaces, reaching), walking (e.g. with head turning, changing speed, tandem walk, stair climbing), and transferring (e.g. changing postures as during sit-to-stand or lateral transfers with or without arm use).

The clinical utility of the balance measures was evaluated according to Tyson and Connell²³ on the basis of (a) tool administration, analyses, and interpretation time (a score of 3 = <10 minutes to complete; 2 = 10-30 minutes; 1 = 30-60 minutes; 0 = >60 minutes), (b) associated cost (3: <£100; 2: £100-£500; 1: £500-£1000; 0: >£1000 or unknown), (c) need of specialized equipment and training (2 = no; 1 = yes, but simple and clinically feasible; 0 = yes, but not clinically feasible), and (d) ease of portability (2 = easily; 1 = portable in a briefcase or trolley; 0 = no or very difficult). According to Tyson and Connell (2009), a score of $\geq 9/10$ suggested a measure could be recommended for clinical use (i.e. high clinical utility). As balance consists of many components,¹⁵ and may be evaluated during different tasks (e.g. sitting, standing, walking, transferring), one would expect some clinically useful measures to take more than ten minutes to complete. Hence, we have lowered the cut-off score for clinical utility to 8; measures scoring 8/10 or greater had high clinical utility.

For the measures with high clinical utility, the following information was synthesized: (a) the psychometric properties (i.e. validity, reliability, and responsiveness) established in the SCI population, and (b) the comprehensiveness of each measure. Validity is the degree to which an instrument measures what it is intended to measure in a given population.³² The validity of a measure can be evaluated by comparing its score to that of a gold standard measure (criterion validity), which is administered at the same time (concurrent validity) or precedes the gold standard test with the aim of predicting its outcome (predictive validity). Validity may also be evaluated by testing the underlying concept of interest (construct validity).³² Convergent validity, a type of construct validity, is demonstrated when the measure in question correlates with another measure of the same concept.³¹ Conversely another type of construct validity, divergent validity, is demonstrated when no correlation is found between the measure in question and another measure known to examine a different construct.³² Reliability refers to the consistency of a measure to yield the same results in a given population.³¹ It is tested by comparing the

results of a measure obtained over two time points when no real change will have occurred (test-retest reliability), or by comparing results when one or two raters consistently administer and score the measure (intra- and -inter rater reliability, respectively).³² Internal consistency is a type of reliability that evaluates the extent to which items in a scale capture the same concept.³¹ Responsiveness is the ability of an instrument to detect change in the concept that is being measured.³² Comprehensiveness was evaluated using the nine operational definitions of balance¹⁵ that were adapted from the original six domains of the Systems Framework for Postural Control.¹⁶ If the balance components of a measure were previously identified by Sibley *et al.*,¹⁵ those identified components were reported here. For measures not assessed by Sibley *et al.*,¹⁵ comprehensiveness was evaluated independently by two researchers (TA with AO) with a third researcher (KM) resolving discrepancies for 11/63 (i.e. 17.5%) ratings across seven scales.

Results

A total of 2820 abstracts were obtained after de-duplication, and 222 were retained for full-text screening (Figure 1). Following full-text review, 127 articles were included. One of the articles was written in Korean³³ for which data extraction was completed with the help of a person proficient in Korean. The supplementary tables S1 and S2 summarize the data extracted from each study.

Participants in these studies had a wide range of characteristics in terms of neurological level of injury (C1 to L5), time since injury (0.1–48 years), and age (15–85.7 years). Forty-two percent of included studies ($n = 54$) involved individuals with motor incomplete injuries (i.e. AIS C and D), 29% of studies ($n = 36$) included motor complete injuries (i.e. AIS A and B), and 22% of studies ($n = 28$) included both motor incomplete and motor complete injuries. The remaining 7% of studies ($n = 9$) did not specify completeness level of the participants. The majority of studies included individuals with SCI solely, whereas 6% of studies ($n = 7$) also included other populations, such as traumatic brain injury,^{34,35} labyrinthine loss,³⁶ stroke,³⁷ Parkinson's disease,³⁸ amputation,³⁹ and polio.⁴⁰

Quality of studies

The majority of studies ($n = 124$, 98%) collected data prospectively; only one study reported data from a retrospective chart review.⁴¹ Two studies^{6,42,43} used a mix of prospective and retrospective data collections (i.e., asking participants about falls experienced in the past

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram.

was considered a retrospective collection⁶). More than half of the studies ($n = 74$, 58%) provided adequate information on participant characteristics including age, sex, level of injury, AIS level, and time since injury, whereas six (5%) studies did not provide sufficient information (>2 missing items), and 47 (37%) studies provided partial (1-2 missing items) information. With respect to inclusion/exclusion criteria, 72 (57%) studies stated detailed inclusion/exclusion criteria, whereas 30 (23%) studies provided only one to two criteria. Twenty-five (20%) studies did not state any inclusion/exclusion criteria. Few studies used population- or community- based samples (one and six, respectively), with the majority ($n = 69$, 54%) of studies recruiting participants according to convenience. Forty percent ($n = 51$) of the included studies did not report the recruitment strategy used. Thirteen percent ($n = 17$) reported the validity, reliability, or responsiveness of the measures being used in the study. The supplementary table S3 summarizes the quality evaluation for each study.

Balance measures used with individuals with SCI

A total of 31 balance measures were identified in this review as meeting inclusion/exclusion criteria. Eleven of these measures evaluated a biomechanical construct; for example, COP or COM related measures^{17,43} and instrumented gait variables⁴⁴ (Table 2). There was considerable heterogeneity in how the biomechanical constructs were measured; however, all measures fit into one of the groupings listed in Table 2. The most commonly used biomechanical grouping was COP or COM ($n = 59$, 46%), followed by EMG ($n = 12$, 9%) and forces or torques ($n = 9$, 7%).

Measures of COP or COM were used to assess balance during all four tasks – sitting,^{45–48} standing,^{17,49} walking⁴⁴ and transfers.⁵⁰ EMG was utilized to evaluate muscle activity during sitting^{50–52} and standing.^{19,53} Direct (e.g. ground reaction forces and torques) and indirect (e.g. stabilization and destabilization forces) measures of forces or torques were used to assess balance during sitting,^{40,54,55} walking,^{20,56,57} and transfers.⁵⁸

Table 2 Clinical utility and tasks evaluated by balance measures.

Balance Measure	Number of studies	Clinical Utility Score (/10)	Tasks Evaluated
Groupings By Biomechanical Construct			
a) COP/COM	59	0	(S _i , S _a , W, T)
b) EMG	12	1	(S _i , S _a)
c) Forces/Torques	9	2	(S _i , W, T)
d) Joint Angles using motion capture	7	0	(S _i , S _a)
e) Instrumented Reaching Distance	5	0	(S _i)
f) Instrumented Gait Variables	3	0	(W)
g) Reaction/Movement Times	4	0	(S _i)
h) *Others (4)	4	0	(S _i , S _a , T)
Balance Scales			
a) Berg Balance Scale	43	8	(S _i , S _a , T)
b) Functional Reach Test	21	10	(S _i , S _a)
c) Dynamic Gait Index	3	8	(W)
d) Tinetti Scale	2	9	(S _i , S _a , W, T)
e) Mini-BESTest	1	8	(S _a , W, T)
f) Activity Based Level Evaluation	1	8	(S _i , S _a , W, T)
g) Clinical Test of Sensory Organization and Balance	1	9	(S _i)
h) Test Table Test	1	10	(S _i)
i) Motor Assessment Scale	1	10	(S _i)
j) Sitting Balance Score	1	10	(S _i)
k) Romberg Test	1	10	(S _a , W)
l) Community Balance and Mobility	1	8	(S _a , W)
m) Balance CAT	1	10	(S _i , S _a , T)
n) Body Sway using Sway Meter	1	8	(S _i , S _a)
o) Standardized Obstacle Clearing Tests	2	9	(W)
p) T-shirt test	3	10	(S _i)
q) Timed Standing	1	10	(S _a)
r) Timed Tandem Stance	1	10	(S _a)
s) Seated Reaction to Perturbation	1	10	(S _i)
t) Five Times Sit-to-Stand Test	1	9	(T)

S_i= sitting; S_a= standing; W = walking; T = transfers; *Others include Damping Factor, Linear Momentum, Trunk Stiffness, Fall Threshold.

COP, Center of Pressure; COM, Center of Mass; EMG, Electromyography; mini-BESTest: mini-Balance Evaluation Systems Test; Balance CAT, Balance Computerized Adaptive Test.

Some biomechanical groupings captured balance during a single activity: Instrumented reaching distance,^{59,60} reaction/movement time,^{61,62} damping

factor,⁶³ and trunk stiffness⁶⁴ were utilized to assess balance during sitting, and mainly in individuals with motor complete injuries. Instrumented gait variables and linear momentum were utilized to capture balance during walking^{42,44,65} and transfers,⁵⁰ respectively. Walking balance was assessed only in individuals with AIS D classification.

Twenty balance measures identified in the review were balance scales, many of which were intended for use in clinical environments. Some balance scales assessed balance during a single activity (e.g. Functional Reach Test (standing and modified; FRT), Romberg sign, Dynamic Gait Index (DGI)), whereas other balance scales included more than one task (e.g. BBS, mini-Balance Evaluation Systems Test (mini-BESTest)) (Table 2). The most commonly used balance scale was the BBS (n = 43, 34%), followed by the FRT (n = 21, 17%), performed in sitting (n = 18, 14%), standing (n = 2, 2%) or both sitting and standing (n = 1, 1%). The remaining balance scales identified were used infrequently (i.e. in ≤3 studies) with individuals with SCI (see Table 2).

Twelve balance scales evaluated sitting balance. Eight of these assessed the task of sitting alone (i.e. modified FRT,^{33,52,61,66–81} Test Table Test,³⁹ Motor Assessment Scale,⁸² Sitting Balance Score,⁸² Sway Meter,⁶⁹ Clinical Test of Sensory Organization and Balance,⁷⁰ T-shirt Test,^{68,69,83} and Seated Reaction to Perturbation⁸⁴), with the modified FRT most commonly used (n = 19, 15%). The modified FRT was used to assess sitting balance in individuals with motor complete and incomplete injuries. Four scales (BBS,^{6,17,34,37,38,41–44,56,57,65,70,75,85–113} Activity-Based Balance Level Evaluation (ABLE),¹¹⁴ Tinetti,^{43,115} and Balance CAT¹⁰³) assessed sitting balance along with balance during other tasks and were used with individuals with complete and incomplete injuries. Similarly, 11 balance scales evaluated standing balance in SCI; five scales examined standing balance in isolation (standing FRT,^{109,116} Traditional Romberg,¹¹⁷ Sway Meter,¹¹⁸ Timed Standing¹¹⁹ and Timed Tandem Stance¹²⁰) and six examined standing along with other tasks (BBS, ABLE,¹¹⁴ Tinetti,^{43,115} mini-BESTest,¹²¹ Community Balance & Mobility Scale (CB&M),⁴¹ and Balance CAT¹⁰³). All of these scales were used in individuals with incomplete injuries, except the BBS^{6,37,70,92,108} and ABLE,¹¹⁴ which were also used in individuals with complete injuries.

Seven scales included an assessment of balance ability during walking; three of which focused solely on this task (DGI,^{38,44,95} Walking Romberg,¹¹⁷ Obstacle Clearance Test¹²²). As walking requires some lower

extremity motor output, the DGI and Obstacle Clearance Test were used in individuals with motor incomplete injuries only. The severity of injury of the participants who completed the Walking Romberg test was not specified.¹¹⁷ Scales that included an assessment of balance during walking along with other tasks were the ABLE, Tinetti, Mini-BESTest, and CB&M. Three scales, the ABLE, DGI and CB&M, included stair climbing.

The review identified only one balance scale that assessed balance during a transfer task (the Five Times Sit-to-Stand);¹⁰⁹ however, balance ability during some transfer activities such as lateral seated transfers, sit-to-stand and/or stand-to-sit was assessed as part of the BBS, ABLE,¹¹⁴ Tinetti,^{43,115} mini-BESTest,¹²¹ and Balance CAT.¹⁰³

Clinical utility of the balance measures

Of the 31 balance scales and balance groupings, 20 scored ≥ 8 on the clinical utility scale,²³ and thus were considered to have high clinical utility (see Table 2 for total scores, supplementary table S4 for score breakdown). The measures with high clinical utility were all balance scales intended for use in clinical environments such as the BBS, mini-BEST, and FRT. These measures are inexpensive and do not require specialist training or equipment; however, some require structures such as stairs and ramps, and this reduced their portability rating. All measures based on biomechanical constructs scored 0-2 on the clinical utility scale suggesting low clinical utility.

Comprehensiveness of clinical measures

Components of balance captured by each balance scale are shown in Table 3. Some of the measures did not provide enough information to evaluate comprehensiveness, such as the T-shirt Test,^{68,69,83} Timed Standing,¹¹⁹ Timed Tandem Stance,¹²⁰ and Seated Reaction to Perturbation.⁸⁴ All other scales captured at least two components of balance and none captured all nine components. The mini-BESTest was the most comprehensive scale, as it captured all components except Functional Stability Limits. Each balance component was captured by at least one of the scales. Static stability and anticipatory postural control were the most commonly assessed components (12 scales each), whereas verticality was captured by only the mini-BESTest.

Psychometric properties

At least one type of validity (construct, concurrent, discriminative, predictive, convergent, content, or criterion) and at least one type of reliability (test-retest, interrater, intra-rater, or internal consistency) was

established in the SCI population for seven balance scales including BBS, FRT, ABLE, Test Table Test, Motor Assessment Scale, Sitting Balance Score, and CB&M (see Table 4). Reliability, but not validity, was established for the Tinetti Scale⁴³ and the Five Times Sit-to-Stand Test¹⁰⁹ in the SCI population. The psychometric properties of the BBS and FRT have been established in individuals with wide spectrum of injury characteristics. For example, both measures have been validated in individuals with subacute^{69,79,91,101} and chronic injuries.^{6,80,109}

Since most BBS items require standing without aids or braces, it has been used and validated in individuals with motor incomplete (AIS C & D) injuries. In contrast, the FRT (completed in standing) has been validated in individuals with motor incomplete injuries¹⁰⁹ and the modified FRT has been validated in motor complete (AIS A & B)^{66,74} and incomplete⁶⁰ injuries. The BBS was shown to have interrater⁶ and intrarater⁴³ reliability, as well as construct⁹¹ and concurrent^{6,101} validity. However, the BBS was unable to predict those at risk of falls^{6,109} or discriminate between those with tetraplegia and paraplegia.¹⁰¹ The FRT was shown to have test-retest reliability by multiple researchers^{69,79} and to possess interrater reliability.¹⁰⁹ With respect to validity, the FRT has convergent⁷⁹ and concurrent⁶⁰ validity, and may be better able to predict those at risk of falling.¹⁰⁹

Only four (3%) studies evaluated the responsiveness of a balance scale in individuals with SCI.^{43,81,91,123} All four of these studies established the responsiveness of BBS in individuals with subacute or chronic motor incomplete (AIS C or D) SCI. Another study found the responsiveness of the Tinetti Scale to be low compared to that of the BBS in individuals with chronic AIS D SCI.⁴³ In addition, one study also established the responsiveness of the modified FRT in individuals during the early stage of recovery; however the scale may have a ceiling effect.⁸¹

Discussion

We completed a systematic review following PRISMA guidelines to describe the current state of the use of balance measures for transferring, sitting, standing and walking activities among the SCI population. A total of 127 studies were found to assess balance in individuals with SCI with all levels of neurological damage and injury severity represented. Thirty-one balance measures were identified; 11 measured a biomechanical construct, and 20 were balance scales primarily intended for use in clinical environments. The majority of studies were prospective assessments that provided adequate

Table 3 Comprehensiveness of the clinical measures as per the modified Systems Framework for Postural Control.¹⁵

Scale	Static Stability	Underlying Motor Systems	Functional Stability Limits	Verticality	Reactive Postural Control	Anticipatory Postural Control	Dynamic Stability	Sensory Integration	Cognitive Influences	Total
Berg Balance Scale	X	X	X			X	X	X		6
Functional Reach Test		X	X			X				3
Dynamic Gait Index		X				X	X	X	X	5
Tinetti	X	X	X		X	X	X	X		7
Mini-BESTest	X	X		X	X	X	X	X	X	8
ABLE	X	X	X		X	X	X	X		7
CTSIB	X	X						X		3
Test Table	X	X	X			X				4
Motor Assessment Scale	X		X			X				3
Sitting Balance Score	X				X					2
Romberg	X						*	X		2 or 3
Community Balance and Mobility Balance CAT	X	X				X	X	X	X	6
BSSM	X		X				X			5
SOCT						X			X	2
FTSST		X				X				3
Total	12	11	7	1	4	12	8 or 9	9	4	

*Dynamic Stability assessed in walking Romberg, but not in standing Romberg.

Mini-BESTest, mini-Balance Evaluation Systems Test; ABLE, Activity-Based Level Evaluation; CTSIB, Clinical Test of Sensory Organization and Balance; Balance CAT, Balance Computerized Adaptive Test; BSSM, Body Sway Using Sway Meter; SOCT, Standardized Obstacle Clearing Tests; FTSST, Five Times Sit-to-Stand Test.

information about study inclusion and participant characteristics; however, about half of the studies recruited samples of convenience, thereby increasing the risk of bias in the research. The clinical utility, comprehensiveness, and psychometric properties of each balance scale were considered in order to provide recommendations concerning the assessment of balance control in individuals with SCI. Although no single balance scale had high clinical utility, strong psychometric properties and comprehensiveness, the mini-BESTest and/or ABLE may fill this gap upon further testing of their psychometric properties as both scales are comprehensive and possess high clinical utility.

Among the studies that evaluated a biomechanical construct, measures of COP or COM were the most common and were used to evaluate balance across all tasks – sitting, standing, walking and transferring. Not surprisingly, all groupings of biomechanical constructs rated poorly on the scale of clinical utility ($\leq 2/10$)

thereby limiting the likelihood of use in clinical environments. Among the balance scales identified in this review, the BBS was the most frequently used, followed by the FRT. Both had high clinical utility, but they were not the most comprehensive scales. Although both BBS and FRT have support for their validity,^{74,79,91,101} reliability^{6,43,74} and responsiveness^{91,123} among individuals with subacute and/or chronic SCI, the BBS was unable to predict falls in individuals with incomplete SCI.^{6,109} The FRT may have more promise as a means to predict falls in individuals with SCI as compared to the BBS.¹⁰⁹

Ideally, a measure of balance for the SCI population will be comprehensive, psychometrically-sound and have high clinical utility. All balance scales identified in this review had high clinical utility (i.e. $\geq 8/10$), but few had established psychometric properties in the SCI population, with the exception of the BBS and FRT, as detailed above. Further, most scales were lacking in

Table 4 Types of validity and reliability tested for different non-biomechanical measures.

Scale	Study	Population	Validity	Reliability
Berg Balance Scale	Datta <i>et al.</i> ⁹¹	Subacute - chronic ^b AIS C - D	☑ Construct Principal Component Analysis	
	Lemay & Nadeau ¹⁰¹	Subacute - chronic ^b AIS D	☑ Concurrent Correlation with walking tests	
	Wirz <i>et al.</i> ⁶	Chronic ^b AIS A - D	☑ Discriminative No significant difference between individuals with paraplegia and tetraplegia ☑ Concurrent Correlated with mobility measures, fear of falling and motor scores ☑ Predictive Could not differentiate fallers from non-fallers	☑ Interrater
	Srisim <i>et al.</i> ¹⁰⁹	Chronic ^a AIS C - D	☑ Predictive No significant difference between non-multiple fallers and multiple fallers	☑ Interrater
	Tamburella <i>et al.</i> ⁴³	Sub-acute - chronic ^a AIS D		☑ Intra-rater
Modified Functional Reach Test	Sprigle <i>et al.</i> ⁷⁹	Sub-acute - chronic ^b AIS levels not reported	☑ Convergent Correlation with ADL tasks ☑ Discriminative Differentiate between Cx from Tx and Lx impairment levels	☑ Test-retest
	BoswellRuys <i>et al.</i> ⁶⁹	Subacute - chronic ^a AIS A -D	☑ Discriminative Differentiate between higher (AIS A, C6-T7) from lower (AIS A-D, T8-L2) level impairments Differentiate between acute and chronic lesions	☑ Test-retest
	Lynch <i>et al.</i> ⁷⁴	Chronicity not reported ^c AIS A-B	☑ Discriminative Differentiate between individuals with C5-6 and T10-12, and between T1-4 and T10-12, but not between C5-C6 and T1-T4	☑ Test-retest
	Adegoke <i>et al.</i> ⁶⁶	Subacute - chronic ^b Complete and Incomplete (unable to stand)	☑ Discriminative No significant difference between three groups based on level of injury (C5-T1, T6-T8 and T10-L1)	☑ Test-retest
	Field-Fote & Ray ⁶⁰	Chronic AIS C - D ^a	☑ Concurrent Correlation with center of pressure excursion	☑ Test-retest
Standing Functional Reach Test	Sprigle <i>et al.</i> ⁸⁰	Chronic ^a AIS level not reported		☑ Test-retest
	Srisim <i>et al.</i> ¹⁰⁹	Chronic AIS C - D ^a	☑ Predictive Prediction of falls with 73% sensitivity and 75% specificity	☑ Interrater
	Ardolino <i>et al.</i> ¹²⁴	Chronicity not reported ^c AIS C - D	☑ Content Through experts' opinion ☑ Construct Principal Component Analysis ☑ Discriminant Differentiate between 3 different groups - "walker", "stander", and "wheelchair-user"	☑ Internal Consistency
Test Table Test	Pernot <i>et al.</i> ³⁹	Chronic ^a AIS A - D	☑ Criterion Correlation with "gold standard" balance perturbation task and center of pressure excursion	☑ Interrater
Motor Assessment Scale	Jorgenssen <i>et al.</i> ¹²⁵	Subacute - chronic ^a AIS A-D	☑ Convergent Correlation with injury level, AIS, and Functional Independence Measure scores	☑ Interrater
Sitting Balance Score	Jorgenssen <i>et al.</i> ¹²⁵	Subacute - chronic ^a AIS A-D	☑ Convergent Correlation with injury level, AIS, and Functional Independence Measure scores	☑ Interrater
Community Balance and Mobility Tinetti	Chan <i>et al.</i> ⁴¹	Subacute AIS C - D ^a	☑ Convergent Correlation with Berg Balance Scale, 6-Minute Walk Test, and 10-Meter Walk Test	☑ Internal Consistency
	Tamburella <i>et al.</i> ⁴³	Subacute - chronic ^a AIS D		☑ Intrarater

Continued

Table 4 Continued

Scale	Study	Population	Validity	Reliability
Five Times Sit-to-Stand Test	Srisim <i>et al.</i> ¹⁰⁹	Chronic AIS C – D ^a	☑ Predictive No significant difference between non-multiple fallers and multiple fallers	☑ Interrater

(*clearly defined by authors; [†]not clearly defined by authors but defined based on time since injury data provided in study; [‡]not defined in study nor were time since injury data provided). ☑ indicates that psychometric property was established. ☒ indicates that psychometric property was tested, but not established. ^aclearly defined by authors; ^bnot clearly defined by authors but defined based on time since injury data provided in study; ^cnot defined in study nor were time since injury data provided.

TSI time since injury (≤ 6 months: subacute; >6 months: chronic).

AIS, American Spinal Injury Association Impairment Scale; ADL, Activities of Daily Living; Cx, Cervical; Tx, Thoracic; Lx, Lumbar

Please refer to the original publication for details concerning the psychometric evaluation and results of each individual study.

comprehensiveness. The balance scales found to be the most comprehensive were the Tinetti Scale, the mini-BESTest and the ABLE. The Tinetti Scale and ABLE evaluated seven of the nine domains of postural control, while the miniBESTest addressed eight. In contrast, most other balance scales used with individuals with SCI included five or fewer domains of postural control. As found in previous literature,¹⁵ some balance domains (i.e. static stability, underlying motor systems, anticipatory postural control and sensory integration) were included in most scales. The domains of verticality, reactive postural control, and cognitive influences were less frequently incorporated into the balance scales, with only the mini-BESTest including all three. The mini-BESTest, however, lacks an assessment of sitting balance, whereas the Tinetti Scale and ABLE captured balance during all four tasks - sitting, standing, walking, and transferring.

Despite the comprehensiveness and high clinical utility of the mini-BESTest, ABLE and Tinetti Scale, their psychometric properties among the SCI population are not well-established. The Tinetti Scale does have high interrater reliability, but has low responsiveness among individuals with sub-acute and chronic AIS D SCI.⁴³ One study established the validity (content, construct and discriminant) and internal consistency of the ABLE among individuals with incomplete and complete SCI.¹²⁴ Another study published in June 2017 (i.e. after this review's search date) demonstrated internal consistency and high construct validity of the mini-BESTest among individuals with chronic AIS D SCI.¹²⁵ Hence, the mini-BESTest and ABLE are promising measures of balance for clinical use with individuals with SCI, and the SCI-specific psychometric properties of these scales should be further established.

This systematic review evaluated 19 balance scales for the SCI population, whereas the SCI EDGE Task Force reviewed only seven balance measures.²⁶ The discrepancy likely resulted from the differing methodology

used to identify balance measures used with this population, the differing search dates (i.e. our review includes more recent literature), and the differing criteria for inclusion (i.e. Kahn *et al.*²⁶ included measures for which the psychometric properties had previously been investigated). As a result, our recommendations concerning the best-available balance measures to use clinically, as well as what knowledge gaps exist, differ from the SCI EDGE Task force.²⁶

With respect to knowledge gaps, the results of this review highlight the need for further research and development in several areas of balance assessment for the SCI population. However, our review has identified differing and more specific gaps than the work by Kahn and colleagues.²⁶ For example, Kahn *et al.*²⁶ suggested that the field lacked a measure of ambulatory balance; however, our review identified seven scales that include assessment of walking balance. From the results of our systematic review, we have identified three gaps in balance assessment for individuals with SCI. First, the psychometric properties of the most comprehensive balance scales (i.e. Tinetti Scale, mini-BESTest and ABLE) should be further evaluated in individuals with sub-acute and chronic SCI. These investigations should include identification of cut-off scores identifying individuals at a risk of falls, if possible. The sample sizes required to adequately power these psychometric studies are often high,¹²⁶ which can be a challenge for research involving low-prevalence conditions, such as SCI. Second, as few studies to date have investigated the responsiveness of balance scales in individuals with SCI,^{42,81,91,123} there is a need to identify balance scales that are responsive to change. Third, the development of a comprehensive scale that evaluates balance during transfers in isolation is warranted. Transferring is an important functional task that is known to place wheelchair-users with SCI at risk of falls.¹¹ The Five Times Sit-to-Stand Test was identified in this review; however, it evaluates only two of the nine domains of

postural control. Further, Srisim *et al.*¹⁰⁹ reported that 25% of the participants with incomplete SCI were unable to perform the Five Times Sit-to-Stand Test in their study, suggesting a floor effect. The 30-second Sit-to-Stand Test,¹²⁹ which does not require the performance of a minimum number of sit-to-stand transfers, may be more appropriate for the incomplete SCI population. Another measure of transfer skill for the SCI population was returned in the search (the Transfer Assessment Instrument^{127,128}); however, it was excluded as it was deemed not to assess balance ability.

Study limitations

There are a few study limitations to note. First, the reliance on samples of convenience in 54% of the studies places the findings at a greater risk of bias. Second, all but one of the included studies were written in English, even though we did not restrict the language in the search. This observation may suggest that the generalizability of the results is limited geographically. Third, there may be measures of walking or mobility that indirectly evaluate balance control, such as the 10-meter Walk Test, 6-minute Walk Test and Timed Up and Go, that were not included in this review. Similarly, measures of the psychological components of balance control (i.e. balance confidence or self-efficacy, fear or concern about falling) were outside of the scope of this review; however, measures of mobility or balance self-efficacy may provide valuable insight into one's fall risk. Fourth, as only four studies evaluated the responsiveness of a balance scale, our review provides little insight into this psychometric property of balance measures for SCI. There is a little consensus on how to accurately measure the responsiveness of a measure¹³⁰ and the variety of scoring methods used across the identified balance scales may affect responsiveness. As mentioned above, this is a topic worthy of future research.

Conclusion

In this review we identified the measures of balance that have been used with the SCI population, as well as areas of balance assessment for SCI in need of further research. To-date no single balance scale meets all criteria of a useful balance scale – high clinical utility, strong psychometric properties and inclusive of all domains of postural control (i.e. comprehensive). Following further evaluation of their psychometric properties, the mini-BESTest and ABLE may fill this need.

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