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Original Research

Evaluating Intrinsic Fall Risk Factors After Incomplete Spinal Cord Injury: Distinguishing Fallers From Nonfallers

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KEYWORDS
Accidental falls;
Ambulation;
Falls;
Spinal cord injuries;
Rehabilitation;
Walking

Abstract *Objective:* To determine whether performance on measures of lower extremity muscle strength, sensory function, postural control, gait speed, and balance self-efficacy could distinguish fallers from nonfallers among ambulatory individuals with spinal cord injury or disease (SCI/D).
Design: Prospective cohort study.
Setting: Community.
Participants: Individuals (N=26; 6 female, aged 58.9±18.2y) with motor incomplete SCI/D (American Spinal Injury Association Impairment Scale rating C [n=5] or D [n=21]) participated. Participants were 7.5±9.1 years post injury. Seventeen participants experienced traumatic causes of spinal cord injury.
Main Outcome Measures: Participants completed laboratory-based and clinical measures of postural control, gait speed, balance self-efficacy, and lower extremity strength, as well as proprioception and cutaneous pressure sensitivity. Participants were then followed for up to 1 year to track falls using a survey. The survey queried the circumstances and consequences of each fall. If a participant's number of falls equaled or exceeded the median number of falls experience by all participants, they were classified a faller.

List of abbreviations: ABC, Activities-specific Balance Confidence; AP, anteroposterior; COP, center of pressure; EC, eyes closed; EO, eyes open; IQR, interquartile range; ML, mediolateral; SCI/D, spinal cord injury or disease; 10MWT, 10-m walk test.

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Results: Median follow-up duration was 362 days and median time to first fall was 60.5 days. Fifteen participants were classified as fallers. Most falls occurred during the morning or afternoon (81%), at home (75%), and while walking (47%). The following laboratory-based and clinical measures distinguished fallers from nonfallers ($P<.05$): measures of lower extremity strength, cutaneous pressure sensitivity, walking speed, and center of pressure velocity in the mediolateral direction.

Conclusions: There are laboratory-based and clinical measures that can prospectively distinguish fallers from nonfallers among ambulatory individuals with spinal cord injury. These findings may assist clinicians when evaluating their patients' fall risk.

Falls are a common occurrence after spinal cord injury or disease (SCI/D), especially among ambulatory individuals.[1] A variety of biological (eg, muscle weakness, balance deficits, spasticity), behavioral (eg, inattention, fear of falling, risk taking), and environmental (eg, uneven ground, low lighting) factors contribute to the fall risk of ambulators with SCI/D.[1] While the physical consequences of falls (ie, injury, hospital admission) are well known, the psychosocial effects of falling are less recognized.[2,3] Individuals living with SCI/D report that falling has a significant, detrimental effect on their ability to work, parent, perform self-care, and participate in leisure activities.[3] Moreover, falls and fall risk affect emotional well-being, with feelings of frustration, vulnerability, fear, and loss of dignity reported.[2,3] Among ambulatory individuals with chronic SCI/D, 50%-67% report a fear of falling.[4,5] This fear can lead to self-imposed restrictions in mobility and participation in life roles,[6] which may perpetuate further decline in emotional well-being, physical function, and quality of life.[3]

Because of the detrimental effect of falls, there is an emphasis on fall prevention in SCI/D rehabilitation.[7,8] A key fall prevention initiative is the use of screening tools to gauge fall risk[8]; however, tools that query the presence/absence of general fall risk factors were reported to lack clinical utility for the SCI/D population.[7,8] Clinicians report that almost all individuals with SCI/D score as having a high fall risk on these tools.[7,8] More sensitive, clinical measures may be more appropriate for assessing fall risk after SCI/D.

A recent systematic review and meta-analysis examined the ability of clinical balance measures to distinguish fallers from nonfallers among the ambulatory population with SCI/D.[9] The Berg Balance Scale was the only clinical measure found to have moderate discriminative ability.[9] While the meta-analysis focused on clinical balance scales,[9] there are other measures that may distinguish fallers from nonfallers. For example, among older adults, slowed gait speed is a marker of falls[10,11] and has been suggested to predict recurrent falls in ambulatory individuals with SCI/D.[12] Another predictor of fall status among older adults is balance/falls self-efficacy,[13] defined as the "perceived self-confidence at avoiding falls during essential, relatively non-hazardous activities."[14(p36)] Impairments in body structure and function, such as reduced lower extremity muscle strength and impaired postural control, are also known to be associated with falls in older adults[15,16] and are perceived to be contributing factors to falls among individuals with SCI/D.[2] However, to date there has been little investigation into whether these measures, many of which are routinely used in SCI/D clinical practice, are able to differentiate individuals with SCI/D who are likely to fall from those who are not.

Here we report the findings from a prospective cohort study that examined the association between the occurrence of falls among individuals with SCI/D and these lesser-studied measures. We aimed to identify whether performance on measures of lower extremity muscle strength, sensory function, postural control, gait speed, and balance self-efficacy could distinguish fallers from nonfallers among ambulatory individuals with SCI/D. We hypothesized that the studied measures would differ significantly between fallers and nonfallers.

Methods

Participants

Individuals with motor incomplete SCI/D were recruited through flyers posted at hospitals and community-based clinics across the province of Saskatchewan, Canada. Interested participants completed a screening interview by telephone. If the participant was deemed eligible, written informed consent was obtained. Ethical approval was granted by the University of Saskatchewan Research Ethics Board and the local Health Region.

Individuals were included if they (1) sustained a traumatic or nontraumatic and nonprogressive SCI/D that resulted in a motor incomplete injury (ie, American Spinal Injury Association Impairment Scale grade C or D), (2) were at least 1 year post injury (ie, chronic injury), (3) were 18 years or older, and (4) were able to walk over ground with a gait aid and/or ankle-foot orthoses but no physical assistance from another person. Participants were excluded if they had another condition that affected their walking or balance (eg, vestibular impairment).

Laboratory-based and clinical assessments

Assessments were completed at the Biomechanics of Balance and Movement Lab, University of Saskatchewan over 2 consecutive days. At one session, a laboratory-based assessment of balance control was completed. At another session, a clinical assessment was completed by a researcher with a background in physical therapy. Demographic (ie, age, sex) and injury-related (ie, neurologic level of injury, time post injury, mechanism of injury) data were also collected.

Center of pressure (COP) sway velocity was measured during quiet standing in mediolateral (ML) and anteroposterior (AP) directions as a measure of balance control. Participants stood on a force plate[a] embedded in the floor (18.25×20 inches) for 60-s trials in eyes closed (EC) and eyes open (EO) conditions. Ground reaction forces were collected with the force plate, from which COP movement was calculated offline using customized software.[b] ML and AP mean sway velocity in both trial conditions were used to calculated the COP sway velocity EC:EO (ie, Romberg ratio). The Romberg ratio was selected because individuals with incomplete SCI/D have increased reliance on vision for postural control.[17,18] COP measures are valid and reliable measures for the population with incomplete SCI/D.[19]

Clinical measures of lower extremity strength, proprioception, cutaneous sensation, walking speed, and balance self-efficacy were completed. Isometric lower extremity strength was tested bilaterally in standardized sitting and lying positions using manual muscle testing of the following 8 muscle groups: hip extensors, hip flexors, hip abductors, hip adductors, knee extensors, knee flexors, ankle plantar flexors, and ankle dorsiflexors.[20] Strength was scored on an ordinal scale with 0=no muscle contraction and 5=normal muscle strength.[21] Half points were adopted between grades 1-5, as outlined in Herbison et al.[21] A total score (/80) was calculated by summing the muscle group scores.

Proprioception of the first metatarsophalangeal and ankle joints was assessed bilaterally. Participants assumed a supine position with their eyes closed while a researcher moved each joint 6 times slowly through 10° of extension/dorsiflexion (ie, up) or flexion/plantar flexion (ie, down). Participants were instructed to state the perceived direction of movement and were assigned a score of 1 for each correct response. Each joint could receive a maximum score of 6 for a total possible score of 24 (ie, 4 joints×6 trials/joint).[22] Cutaneous pressure sensation was assessed using monofilaments[c] with participants in supine. Six different thicknesses were used for the plantar surface of the first toe bilaterally. The monofilaments were applied in order of descending thickness. The researcher applied each monofilament 6 times while the participant's eyes were closed. Participants were instructed to say "yes" if they could feel pressure being applied. A score of 1 was assigned for each correct "yes" response for a total possible score of 72 (ie, 2 first toes×6 monofilaments×6 trials/monofilament).

To measure walking speed, the 10-m walk test (10MWT) was performed. Participants walked in a straight line for 14 m (middle 10m timed) with assistive devices and braces as needed. The 10MWT is valid and reliable among individuals with incomplete SCI/D.[23] Participants performed the 10MWT at a self-selected speed and then a second time at their fastest speed. Walking speed reserve, the difference between fastest and self-selected walking speeds, was also calculated.[24,25]

The Activities-specific Balance Confidence (ABC) Scale was administered to assess balance self-efficacy. Participants were asked to consider 16 different tasks (ie, sweeping, getting onto/off an escalator, walking on icy sidewalks) and rate their confidence in their ability to maintain balance for each task on a continuous scale from 0%-100%. The ABC Scale is a valid and reliable measure for the population with chronic incomplete SCI/D.[4]

Prospective assessment of falls

After the testing sessions, participants were followed up for 1 year to document the occurrence of falls. Participants were provided the following definition of a fall in writing: "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level."[26(p1)] Participants were asked to complete a survey to collect information regarding the circumstances and consequences of each fall. Survey questions were mostly closed ended and queried details of the fall, such as location, time of day, and perceived cause(s).[27,28] Participants were asked to complete the survey within 24 hours of experiencing the fall to reduce recall bias. Participants were given the option to complete a paper and/or electronic version of the survey. Offering a variety of response options has been recommended for survey studies involving individuals with SCI/D.[29] The online survey was administered by a secure system.[d] For participants who opted to complete the paper version of the survey, responses were entered into the online survey platform by a researcher during a follow-up phone interview. Phone interviews were completed every 3 weeks to ensure the fall surveys were being completed and to document changes in participants' health status.

Statistical analyses

Demographics, injury-related data, and laboratory and clinical assessments were reported as mean and SD or frequency counts, as appropriate. Survey data were synthesized with descriptive statistics (eg, frequency counts). For categorical survey data (ie, time of fall, location of fall), a 1-sample chi-square test was used to determine whether the data followed a hypothesized population distribution (ie, no differences in frequency across categories).

At the end of the follow-up period, each participant was classified as a faller or nonfaller based on the number of falls experienced. If a participant's number of falls was equal to or greater than the median number of falls experienced by all participants, they were classified as a faller. If a participant's number of falls was less than the median number of falls experienced by all participants, they were classified as a nonfaller. These definitions of faller and nonfaller were selected because the majority (ie, 78%; CI, 73%-83%) of ambulators with SCI/D fall at least once per year.[1] Defining a fall according to the median number of falls ensured we focused on those individuals with a greater fall risk. Time to first fall was reported as median and interquartile range (IQR).

We hypothesized that the probability of the time to first fall in the study population followed a Poisson distribution. Therefore, a Poisson regression model was used to calculate

Table 1 Demographic and injury-related characteristics

Characteristics	All Participants (n=26)	Fallers (n=15)	Nonfallers (n=11)
Sex (male:female)	20:6	12:3	8:3
Age (y), mean ± SD	58.9±18.2	59.5±18.4	58.0±18.8
Time since injury (y), mean ± SD	7.5±9.1	9.5±11.6	4.6±2.2
AIS (C:D)	5:21	4:11	1:9
Traumatic:nontraumatic	9:17	5:10	4:7
Paraplegia:tetraplegia	11:15	7:8	4:7

Abbreviation: AIS, American Spinal Injury Association Impairment Scale.

the incidence of a first fall in the study population. Because a participant may experience more than 1 fall, which is not an independent event, we decided to measure the population's first fall incidence. Using this model, we investigated the incidence of a first fall in the study population as the dependent variable during the 1 year of follow-up. The time in the model was the number of days elapsed from the beginning of the study until either the first fall or the end of the follow-up, whichever came first. Because of the small sample size, we could not conduct a multiple Poisson regression analysis and instead assessed the effect of each variable in a univariate model. The α level was set at 0.05 for all statistical tests, which were executed on SAS version 9.4[e] or SPSS version 26.[f]

Results

Participants

Twenty-six individuals with SCI/D (table 1) participated between July 2014 and May 2017. Group performance on the laboratory-based assessment of balance control and clinical assessment is reported in table 2. COP data were reported for 20 participants. The reasons for missing COP data included inability to stand independently for the required length of time of the COP data collection (n=4), equipment error (n=1), and participant being deemed an outlier (ie, data exceeded 3 SDs of group mean) (n=1).

Falls data

The median follow-up duration for all participants was 362 days (IQR, 23.25d). Twenty-four participants were followed for at least 307 days, while 2 participants were followed for 96 and 251 days. These 2 participants could not be reached for further follow-up interviews.

Twenty-one participants (81%) experienced at least 1 fall in the follow-up period for a total of 72 falls. The median number of falls was 2. Eleven participants fell under the median (ie, 0 or 1 fall) and 15 participants fell at least twice. Of the 2 participants who were lost to follow-up, one was classified as a faller and the other as a nonfaller.

Median time to first fall was 60.5 days (IQR, 68d) (fig 1). Falls most frequently occurred in the morning (33.3%) or afternoon (45.8%). Three-quarters of falls took place at home, either indoors (47.2%) or outdoors (27.8%). These distributions of responses for both time and location of fall were likely not due to chance ($P<.01$). Just under half of the falls recorded took place while walking. Falls were commonly the result of a slip or weakness/legs giving out (table 3). Thirty falls (42%) resulted in injury, mostly pain or bruises. Five falls resulted in the participants requiring medical attention, and 1 fall led to a hospital admission.

Survival analysis

The COP velocity ratio of EC:EO in the AP direction did not affect the number of falls experienced by participants ($P=.57$); however, as the COP velocity ratio of EC:EO in the ML direction increased, the number of falls experienced also increased ($P=.04$). As self-selected and fast walking speeds increased, the number of falls decreased ($P=.01$ and $P=.04$, respectively); however, walking speed reserve did not affect the number of falls experienced ($P=.38$). As lower extremity strength and lower extremity cutaneous pressure sensation increased, the number of falls decreased ($P<.01$). However, lower extremity proprioception did not affect the number of falls experienced ($P=.50$). Also, balance self-efficacy, as measured on the

Table 2 Performance on laboratory and clinical assessments

Variables	Mean ± SD	Range	Fallers, mean ± SD	Nonfallers, mean ± SD
COP velocity ML ratio EC:EO	1.71±0.56	0.63-2.84	1.83±0.59	1.55±0.52
COP velocity AP ratio EC:EO	2.01±0.76	0.71-4.1	2.02±0.44	2.01±1.07
LE strength (/80)*	61±11	36-74	57±10	66±9
LE proprioception (/24)	19±5	6-24	19±5	20±4
LE cutaneous pressure (/72)	31±15	0-52	26±15	39±11
Walking speed self-selected (m/s)	0.84±0.42	0.09-1.46	0.68±0.3	1.09±0.64
Walking speed fast (m/s)	1.16±0.59	0.10-2.07	0.93±0.43	1.52±0.64
Walking speed reserve (m/s)	0.32±0.22	0.01-0.73	0.25±0.19	0.44±0.24
ABC Scale (%)	67.5±20.2	21.3-95.3	60.0±16.7	78.5±20.1

Abbreviation: LE, lower extremity.

* Total score of 80 consisted of 40 per leg (maximum score of 5 for each muscle group, 8 muscles per leg were tested).

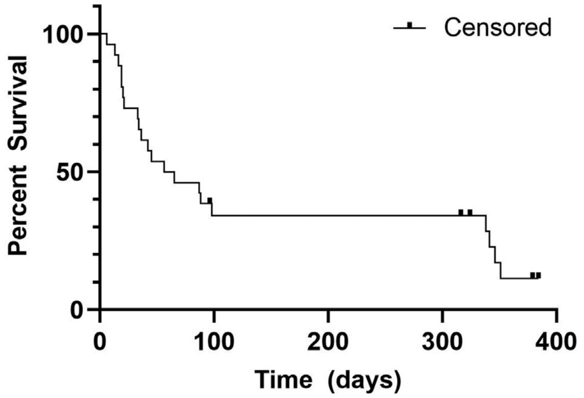

Fig 1 Time to first fall. Participants who did not experience any falls are noted as censored events.

ABC Scale, did not affect the number of falls experienced by individuals with SCI/D ($P=.60$).

Discussion

Through a prospective cohort study, we examined the association between the occurrence of falls and select laboratory-based and clinical measures among ambulatory individuals with SCI/D. Poorer performance on measures of lower extremity strength, cutaneous pressure sensitivity, walking speed, and increased Romberg ratio of COP velocity in the ML direction were associated with the future occurrence of falls.

Among the studied laboratory-based measures, the Romberg ratio of COP velocity in the ML, but not AP, direction distinguished fallers from nonfallers. Maintaining postural control in the ML direction has been suggested to require greater active contribution from supraspinal neural centers and is considered a greater challenge than maintaining postural control in the AP direction.[30] We also found that lower extremity strength was able to distinguish the fallers from the nonfallers in our sample. This finding conflicts with that of Jørgensen et al,[12] who reported no significant differences in the lower extremity motor scores of infrequent fallers and recurrent fallers. One possible explanation for the conflicting results is the number of muscles tested in each study. The lower extremity motor scores includes 5 muscle groups: hip flexors, knee extensors, ankle dorsiflexors, long toe extensors, and ankle plantar flexors.[31] In contrast, we evaluated the strength of 8 muscles, including 4 muscle groups that act at the hip joint. Because muscles at the hip joint are important for postural control, especially in the ML direction,[32,33] it seems reasonable that the evaluation of lower extremity strength used in this study may be more indicative of postural control and hence, fall risk.

Surprisingly, performance on the test of lower extremity proprioception did not distinguish fallers from nonfallers. Proprioceptive deficits have been shown to affect performance on challenging mobility tasks, such as stepping over obstacles, in ambulatory individuals with SCI/D.[34] In this study we used a simple proprioception test that, while possessing clinical utility, may lack sensitivity. Instrumentation, such as the Lokomat[34] or Biodex system,[35] have been used to evaluate lower extremity proprioception and could be used in future studies to confirm or refute our findings.

Table 3 Details of falls

Variables	Details	Count	%
Time of fall*	Afternoon	33	45.8
	Morning	24	33.3
	Evening	13	18.1
	Night	2	2.8
Location of fall*	Home indoors	34	47.2
	Home outdoors	20	27.8
	Community outdoors	11	15.3
	Community indoors	4	5.6
	Work outdoors	2	2.8
	Work indoors	1	1.4
Activity at time of fall	Walking	34	47.2
	Standing	8	11.1
	Climbing stairs	7	9.7
	Changing positions	7	9.7
	Other	7	9.7
	Getting into/out of bed	4	5.6
	Getting into/out of vehicle	3	4.2
	Getting into/out of shower/bath	2	2.8
Reason of fall	Slipped	17	23.6
	Other†	14	19.4
	Legs gave out/weakness	13	18.1
	Tripped	9	12.5
	Spasms in legs	5	6.9
	Poor balance	4	5.6
	Don't know	2	2.8
	Tired	2	2.8
	Moving quickly/rushing	2	2.8
	Doing more than 1 thing	2	2.8
	Was distracted	1	1.4
	Illness	1	1.4

* Distribution of responses likely not due to chance ($P<.01$).

† Other reasons for falls included back spasms, misjudgment of supports, and compromised vision.

As expected, both self-selected and fast walking speeds were able to distinguish fallers from nonfallers; however, walking speed reserve did not. These findings align with prior research in older adults[24] and individuals with multiple sclerosis.[25] Unexpectedly, ABC Scale scores did not discriminate fallers from nonfallers in our participants, despite the 2 groups scoring differently (see table 2). Scores of 67%-69% are associated with a high likelihood of falling among other populations.[13,36] While there is some evidence that ABC Scale scores predict fall status,[13] a recent systematic review concluded that there is limited support for the predictive ability of the ABC Scale among community-dwelling older adults because of a lack of research.[37] Among ambulatory individuals with SCI/D, those with fear of falling were found to have a greater risk of falling.[12] Generally less fear of falling is associated with greater balance self-efficacy (ie, ABC Scale scores) in older adults,[38] although the relationship between these 2 constructs has yet to be established for the population with SCI/D.

Identification of a single measure that can accurately gauge fall risk among individuals with SCI/D is desired by clinicians and health care administrators,[7] yet this may not be realistic. Falls among the population with spinal cord injury result from multiple interacting factors spanning biological, behavioral, socioeconomic, and environmental domains.[1,2,39] A meta-analysis that aimed to identify clinical measures that predict fall risk among ambulatory individuals with SCI/D resulted in conflicting findings.[9] Accurate prediction of fall risk likely requires the integration of a variety of relevant factors that are specific to each individual, a process akin to clinical decision making. One study found that clinician judgment concerning the fall risk of geriatric inpatients was more accurate than 2 commonly used fall risk assessment tools.[40] The findings reported here provide insight into which intrinsic factors clinicians should consider as they evaluate a patient's fall risk.

In this study, most falls occurred in the daytime and at home. These findings are consistent with previous studies examining the circumstances of falls among ambulators and wheelchair users with SCI/D.[5,12,28,41] Individuals with SCI/D have explained that home is a "safe space" where they are less vigilant about preventing falls.[41] Further, higher activity levels during the daytime may explain the high fall occurrence in the morning and afternoon.[41] Consistent with prior research,[5,28] walking was the most commonly performed activity at the time of a fall. This finding is not surprising because human walking is "a particularly challenging balance task."[42(p205)]

Study strengths and limitations

The small sample size and missing laboratory-based data limited the statistical analyses that could be completed. For example, with a greater sample size a receiver operating characteristic curve analysis could be completed to establish cutoff scores for the measures that distinguish fallers from nonfallers. Further, it is possible some statistical tests are underpowered, increasing the risk of type II errors. We did not perform a comprehensive assessment of the many risk factors that may be associated with falls; factors other than those studied here may more effectively distinguish fallers from nonfallers. A strength of this study was the length of fall monitoring (ie, 1y). To our knowledge, only 1 other study has prospectively monitored falls in ambulatory individuals with SCI/D for this length of time.[12] Moreover, only 2 participants (7.7%) were lost to follow-up in our study, a similar rate to that reported by Jørgensen et al (ie, 6.8%).[12]

Conclusions

Poorer performance on measures of lower extremity strength, cutaneous pressure sensitivity, walking speed, and ML postural control in standing were associated with the occurrence of falls among ambulatory individuals with SCI/D. The findings provide insight concerning factors that may identify ambulatory individuals with SCI/D who are at a greater risk of falling.

Suppliers

a. OR6-7 force plates; Advanced Mechanical Technology Inc.
b. MATLAB R2006b; Mathworks Inc.
c. Baseline Tactile Monofilaments; Fabrication Enterprises Inc.
d. Fluid Surveys; SurveyMonkey.
e. SAS version 9.4; SAS Institute, Inc.
f. SPSS version 26; IBM.

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