Functional assessments for predicting a risk of multiple falls in independent ambulatory patients with spinal cord injury

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Background/objectives: Many ambulatory patients with spinal cord injury (SCI) encountered multiple falls and serious consequences after falls, but there was no quantitative practical measure for early identification of individuals at a risk of multiple falls. This study compared the utility of the Berg Balance Scale, Timed “Up & Go” Test, 10-Meter Walk Test, Functional Reach Test (FRT), Step Test, and Five Times Sit-to-Stand Test to predict risk of multiple falls (fall ≥ 2 times) in these individuals.

Methods: Eighty-three independent ambulatory subjects with SCI were assessed for their functional abilities using the six tests. Then, their fall data were monitored prospectively every 2 weeks for 6 months in total. The first 25 subjects were also involved in the reliability tests.

Results: The FRT showed the best predictive ability for the risk of multiple falls (cut-off score ≥ 20 cm, sensitivity = 73%, specificity = 55%, area under the receiver characteristic curve = 0.64, and adjusted odd ratio = 3.18, $P < 0.05$), excellent inter-tester reliability, and good feasibility.

Conclusions: The FRT may be used as a screening tool to predict risk of multiple falls in independent ambulatory individuals with SCI. However, with a moderate level of specificity, a further comprehensive test may be needed to clearly indicate individuals at a risk of falls. In addition, the findings suggest that a higher level of ability increases the risk of multiple falls. Thus, programs for functional integration in an actual environment may be needed to reduce the risk of falls for these individuals.

Keywords: Tetraplegia, Paraplegia, Falls, Balance, Measurement

Introduction

Approximately 34–75% of independent ambulatory patients with spinal cord injury (SCI) experienced at least one fall during 6–12 months.^{1–4} The falls induced not only physical consequences to the patients such as fractures, limited ability to get out into a community and engage in a productive activity, but also psychological ones such as fear of falls that might further restrict physical activities.^{1–5} However, most subjects who fell encountered multiple falls that likely introduced more serious consequences, i.e. patellar and sternum fractures.^{1–4} Therefore, identification of the risk of multiple falls is crucial to prevent possible subsequent injuries after falls in these individuals.

A single fall commonly occurs due to an extrinsic cause, whereas multiple falls are likely associated with intrinsic impairments.^{6,7} Previous studies have reported that major intrinsic factors associated with falls include level of functional independence, physical fitness, gait velocity, reaction time, limit of stability (LOS), and lower extremity muscle strength.^{8–10} These impairments can be quantified using the Berg Balance Scale (BBS), Timed “Up & Go” Test (TUG), 10-Meter Walk Test (10MWT), Functional Reach Test (FRT), Step Test, and Five Times Sit-to-Stand Test (FTSST).^{8,10} Currently, there is no established threshold to predict the risk of multiple falls using these tests in independent ambulatory patients with SCI. The existing evidence likely reported the causes of falls using subjective information from the subjects^{1–5} whereas the data from objective tests may clearly indicate individuals at

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a risk of falls and subsequent injuries. Therefore, this study investigated the applicability of the six functional assessments to predict risk of multiple falls (falls ≥ 2 in 6 months) in independent ambulatory subjects with SCI. The findings were considered in terms of predictive capability, inter-tester reliability and feasibility of the tools.

Methods

Subjects

This is a prospective cohort study in independent ambulatory subjects with SCI from either traumatic causes or non-progressive diseases at a chronic stage of injury (≥ 12 months after SCI) from a tertiary rehabilitation center in Thailand. From the sample size calculation, the study required 83 subjects who had an age of at least 18 years and ability of independent walking of at least 15 m with or without assistive devices (Functional Independence Measure Locomotor scores 5–7). The subjects were excluded if they had medical conditions that might affect participation in the study such as pain in the musculoskeletal system (at rest and with movement) with an intensity more than 5 out of 10 on a visual analog scale, and deformity in the spine or joints that might affect ambulatory ability (i.e. marked kyphosis or scoliosis, leg length discrepancy, and equinovarus or equinovalgus). This study was approved by the local ethics committee and eligible subjects needed to provide written informed consent prior to participation in the study.

Experimental protocol

Subjects were interviewed and assessed for their baseline demographics and SCI characteristics including causes, severity and level of SCI, and time post-onset.¹¹ Then they were assessed for their functional abilities using the six functional assessments in a random order to reduce carrying-over effects due to sequences of the tests that might occur such as fatigue and learning effects. Details of the tests are as follows.

Berg balance scale

The test evaluated the ability to perform 14 sitting and standing activities. Ability to perform each activity was rated using a 5-point ordinal scale ranging from 0 to 4 based on time and ability to execute the activities. Thus, the total scores range from 0 to 56.^{12,13}

Timed “Up & Go” test

Subjects were instructed to stand up from an armrest chair, walk around a traffic cone that was located 3 m away from the chair, and return to sit down on the chair at a maximum and safe speed with or without a

walking device.^{4,14,15} The time was recorded from the command “Go” until the subject’s back was against the backrest of the chair. Subjects performed three trials and the average finding over the three trials was used for data analysis.

10-Meter walk test

Subjects walked at a comfortable speed with or without a walking device along a 10-m walkway. The average time required for the three trials over the 4 m in the middle of the walkway was recorded in order to minimize acceleration and deceleration effects on the outcome.^{14–16}

Functional reach test

The test measured the average longest distance over the three trials that the subjects could reach forward without changing the body base of support (feet lifting or stepping). The reaching distance was measured using a leveled yardstick attached to the wall at the height of the subject’s acromion process.^{17,18}

Step test

This test assessed the time required to complete eight alternative left and right steps onto a 20-cm-height stool at a fast and safe speed. The test recorded the time required from the word “start” until the last foot was placed back on the floor on the eighth repetition.⁶

Five times sit-to-stand test

The test evaluated the time taken to complete five repetitions of the sit-to-stand maneuver from an armless chair at a maximum and safe speed without using the hands. The time was recorded from the command “start” until the subject’s back was against the backrest of the chair, and the average finding over the three trials was used for data analysis.^{14,15,19}

During the tests, subjects did not wear any shoes to minimize effects of different types of shoes on the outcomes and risk of injury. In addition, they had to wear a lightweight safety belt around their waist with a physical therapist walking or being beside the subjects throughout the tests in order to ensure their safety and the accuracy of the tests.

Falls surveillance

After completing the functional tests, the fall data of subjects was monitored every 2 weeks via telephone interview for a total of 6 months. A fall was defined as “an unintentional event that resulted in a person coming to rest on the ground from an upright standing or walking activity as a result of neither a major intrinsic event (stroke or syncope) nor an extrinsic cause.”⁴ If

there was a fall, the information was confirmed by asking related data such as time, place, and consequences of the fall with confirmation from relatives or caregiver. Then the findings after 6 months were used to classify subjects into non-multiple faller (≤ 1 fall) and multiple faller (≥ 2 falls) groups.⁶

Reliability test

The inter-tester reliability of the tools was evaluated in the first 25 subjects who participated in the study using two physical therapists who had clinical experience in patients with SCI over more than 5 years. Prior to participation, the testers were trained to use the same standard methods. Then they concurrently evaluated the ability of each subject using the six tools in a random order with three trials per activity, and a sufficient period of rest between the trials. The average findings over the three trials of each assessor were used to analyze the inter-tester reliability of the tools.

Feasibility of the tests

The feasibility of the tools was considered in terms of the number of subjects who could complete the tests, and the time, area and equipment required to administer the tests.

Statistical analyses

Descriptive statistics were used to explain baseline demographics, SCI characteristics, and findings of the study. The independent samples *t*-test and the χ^2 test were utilized to compare the continuous and categorical data between multiple faller and non-multiple faller groups. The receiver-operating characteristic curves were applied to explore an optimal cut-off score, sensitivity, specificity, and area under the receiver characteristic curve (AUC) for the tests to discriminate ability of multiple faller and non-multiple faller subjects.^{20,21} Then stepwise multiple logistic regression analysis was utilized to determine the effects of the significant baseline data on the predictive ability of the functional tests. The results were reported in terms of an adjusted odds ratio (aOR) with corresponding 95% confidence intervals (95% CIs), and beta (β) coefficients with standard error around the β coefficient. In addition, the intraclass correlation coefficients (ICCs 2, 3) and the standard errors of measurement (SEM) were employed to explain the inter-tester reliability and amount of variation or spread in the measurement errors for the tests, respectively. The highest possible value of the SEM is zero which infers no errors of measurement or a perfectly reliable test.²² The level of significance was set at $P < 0.05$.

Figure 1 Subject participation flowchart.

Results

Fig. 1 illustrates subject participation. Most subjects were males with an average age of 50.34 ± 11.65 years at a chronic stage of SCI and required a walking device. After 6 months, 60 subjects were classified as being in the non-multiple faller group and 23 subjects were placed into the multiple faller group (falls ≥ 2 , range 2–11 times, and the total number of falls = 67). In those with multiple falls, the falls occurred while standing (21 times, 32%), but mostly while walking (40 times, 60%) within the subjects' house (35 times, 52%) and during morning to afternoon time (56 times, 84%). Subjects indicated that the falls occurred due to lower extremity muscle weakness (21 times, 32%) and tripping over an obstacle (20 times, 30%). After falls, two multiple faller subjects had ankle and sternum fractures. Table 1 presents baseline demographics and SCI characteristics of the subjects. There were no significant differences between the groups of all variables, except age and level of injury in which the multiple faller subjects were significantly younger and had a significantly greater ratio of individuals with tetraplegia than the non-multiple faller subjects ($P < 0.05$, Table 1).

Every subject could complete the BBS, TUG, 10MWT, and FRT, but only 38 and 62 subjects could execute the step test and FTSST, respectively (Table 2). The functional abilities of the non-multiple faller and multiple faller subjects demonstrated no significant differences, except for the FRT in which the multiple-faller subjects could reach forward over a significantly longer distance than the non-multiple faller subjects ($P < 0.05$, Table 3). Table 4 presents the cut-off scores, sensitivity, specificity, and AUC of the six functional tests to discriminate ability of the subjects. Among the six tests, the FRT had the best predictive ability for the risk of multiple falls (Table 4). After

Table 1 Baseline demographics and spinal cord injury characteristics of the subjects

Variable	Non-multiple faller (≤ 1 fall) subjects ($n = 60$)	Multiple faller (≥ 2 falls) subjects ($n = 23$)	P value
Age (years)*	52.68 $\pm$ 11.21	44.21 $\pm$ 10.72	0.003**
Body mass index (kg/m ²)*	22.70 $\pm$ 3.79	22.14 $\pm$ 2.95	0.537
Post-injury time (months)*	46.72 $\pm$ 36.42	58.70 $\pm$ 60.03	0.271
Sex: Male [†]	39 (65)	17 (74)	0.438
Cause of injury: Traumatic causes [†]	23 (38)	12 (65)	0.253
Level of injury: Tetraplegia [†]	17 (28)	12 (65)	0.041**
Severity of SCI: AIS C [†]	12 (20)	9 (39)	0.073
Walking device: Yes [†]	37 (62)	12 (65)	0.569

*The data are presented using mean $\pm$ SD and the comparisons between the groups were performed using the independent samples *t*-test.

**Significant difference between the groups.

[†]The data are presented using the number of subjects [*n*(%)] and the comparisons between the groups were executed using the χ^2 test. These variables were categorized as follows; Sex: Male/Female, Cause of injury: Traumatic causes/non-progressive diseases, level of injury: paraplegia/tetraplegia, severity of injury: AIS C/D, Walking device: Yes/No. AIS, American Spinal Injury Association (ASIA) Impairment Scale.

adjusting for the significant baseline data including age, level and severity of SCI, the multiple logistic regression analyses indicated that subjects who could reach forward over at least 20 cm encountered an approximately three times greater risk of multiple falls than those who could reach less than 20 cm ($P < 0.05$, Table 5).

Every test demonstrated excellent inter-tester reliability when analyzed using the ICCs (ICCs (2, 3) = 0.997–1.000, Table 6). However, the SEM data indicated that the FRT had the least amount of data variation, followed by the 10MWT, step test, TUG, FTSST, and BBS, respectively (Table 6). Furthermore, the FRT, step test and FTSST could be completed within a short period of time, and required only a few pieces of equipment and a small area to administer (Table 2). However, only 38 and 62 subjects could complete the step test and FTSST, respectively (Table 2), and consequently the FRT showed the best reliability and feasibility.

Discussion

This study investigated the applicability of six functional tools, including the BBS, TUG, 10MWT, FRT, step test,

and FTSST, to predict risk of multiple falls in independent ambulatory subjects with SCI. Among the six tests, the FRT could clearly distinguish between non-multiple faller and multiple faller subjects ($P < 0.05$, Table 3), and had the best predictive ability for the risk of multiple falls (Tables 4 and 5). Moreover, the FRT showed the best reliability and feasibility to assess functional ability in independent ambulatory subjects with SCI (Tables 2 and 6).

The possible explanation for the best discriminative ability of the FRT might relate to the number of subjects who could complete the tests and the method of test. Every subject could complete the BBS, TUG, 10MWT, and FRT but only the FRT assessed the ability of the subjects without using a walking device. Therefore, the findings might clearly indicate LOS, which is a sensitive factor for detecting balance ability while changing postures of subjects.^{10,23,24} On the contrary, subjects were allowed to use the arms or walking devices while performing the BBS, TUG, and 10MWT in which contribution of the arms could increase the level of ability of the subjects,²⁵ but the results might not truly reflect their ability of balance control and

Table 2 Feasibility data for the tools

Variable	<i>n</i>	Administration time* (minutes)	Equipment** (pieces)	Area
Berg Balance Scale	83 [†]	18.33 $\pm$ 4.49	7	Wide
Timed "Up & Go" Test	83 [†]	2.96 $\pm$ 1.91	3	Wide
10-Meter Walk Test	83 [†]	2.44 $\pm$ 1.10	1	Wide
Functional Reach Test	83 [†]	2.69 $\pm$ 1.03	1	Small
Step test	38 [‡]	1.18 $\pm$ 0.94	2	Small
Five Times Sit-to-Stand Test	62 [§]	2.31 $\pm$ 0.96	2	Small

*The data are presented using mean $\pm$ SD.

**The data are presented using the number of pieces of equipment required.

[†]60 non-multiple faller subjects and 23 multiple faller subjects.

[‡]29 non-multiple faller subjects and 9 multiple faller subjects.

[§]46 non-multiple faller subjects and 16 multiple faller subjects. *n*, the number of subjects who could complete the tests.

Table 3 Functional abilities of non-multiple faller and multiple faller subjects

Variable	Non-multiple faller (≤ 1 fall) subjects ($n = 60$)	Multiple faller (≥ 2 falls) subjects ($n = 23$)	P value*
Berg Balance Scale (score)	35.58 $\pm$ 16.15	42.35 $\pm$ 11.06	0.069
Timed "Up & Go" Test (s)	23.85 $\pm$ 16.04	30.83 $\pm$ 20.29	0.104
10-Meter Walk Test (s)	9.64 $\pm$ 6.79	12.92 $\pm$ 9.56	0.084
Functional Reach Test (cm)	16.23 $\pm$ 12.03	22.63 $\pm$ 8.58	0.025 [†]
Step test [‡] (s)	17.02 $\pm$ 7.92	13.37 $\pm$ 4.63	0.199
Five Times Sit-to-Stand Test [§] (s)	15.69 $\pm$ 6.59	15.00 $\pm$ 5.69	0.712

The data are presented using mean $\pm$ SD.

*P value from the independent samples *t*-test.

[†]Significant difference between the groups.

[‡]Thirty-eight subjects could complete the test in which 29 subjects were non-multiple fallers and 9 subjects were multiple fallers.

[§]Sixty-two subjects could complete the test in which 46 subjects were non-multiple fallers and 16 subjects were multiple fallers.

lower limb function. As a result, these tests were unable to discriminate the ability of multiple faller and non-multiple faller subjects, and had lower predictive ability than the FRT. Since the subjects had very heterogeneous characteristics, the predictive ability of the findings was adjusted using the significant baseline data including age, level and severity of SCI. The findings confirmed that the ability of having forward reach distance of at least 20 cm significantly increased the risk of multiple falls by approximately three times over those who could reach a shorter distance (Table 5).

Wirz *et al.*¹² similarly found that even though the BBS was reliable and related well to other mobility measures, fear of falling, and muscle strength, the test was unable to distinguish between faller and non-faller subjects with SCI. Phonthee *et al.*⁴ contrarily found that the TUG data could clearly discriminate the abilities of faller and non-faller ambulatory subjects with SCI; however, the researchers categorized the subjects into faller (≥ 1 fall) and non-faller (no fall) groups. Previous studies^{6,7} suggested that a single fall (1 fall) likely occurred due to an extrinsic cause whereas multiple falls (≥ 2 falls) were related to intrinsic factors. Therefore, this study divided subjects into multiple faller and non-multiple fall groups in order to clearly indicate the falls that occurred due to intrinsic impairments. Nevertheless, different criteria for subject categorization may cause different findings from the previous report.⁴

For the step test and FTSST, although the tests were performed without using any walking devices, the tests were very demanding which limited the participation of some subjects ($n = 45$ and 21 for those who were unable to complete the step test and the FTSST, respectively). Among subjects who could complete these tests, there were only 9 and 16 multiple faller subjects for the step test and FTSST, respectively. The small number of subject participation may limit the discriminative power and the predictive ability of the tools.

The results indicate that ability of forward reach of at least 20 cm (FRT ≥ 20 cm) had moderate ability to predict risk of multiple falls in ambulatory subjects with SCI (sensitivity = 73%, specificity = 55%, and AUC = 0.64, aOR = 3.18, Tables 4 and 5). The findings implied that subjects with greater LOS or better balance control encountered a higher risk of falls. The results were different from those reported in other groups of subjects where a shorter forward reach distance was associated with a higher risk of falls.^{17,23,24,26} For example, Duncan *et al.*¹⁷ found that elderly who were unable to perform forward reach had an increased risk of recurrent falls 8.07 times (OR = 2.8–23.71) of those who successfully completed the test. Murphy *et al.*²⁵ found that elderly who had FRT distance less than and equal to 8 cm had an increased risk of falls (sensitivity = 73% and specificity = 88%). In addition, Dite and Temple²³ reported that FRT distance of less

Table 4 Cut-off scores and associated data to predict a risk of multiple falls of the 6 tests

Variables	Cut-off scores	Sensitivity (%)	Specificity (%)	AUC
Berg Balance Scale [†] (score)	≥ 40	65	53	0.61
Timed "Up & Go" Test [†] (s)	≥ 26	61	68	0.57
10-Meter Walk Test [†] (s)	≥ 10	56	69	0.57
Functional Reach Test [†] (cm)	≥ 20	73	55	0.64
Step test [‡] (s)	≤ 13	44	48	0.36
Five Times Sit-to-Stand Test [§] (s)	≤ 15	50	50	0.48

Cut-off scores and associated data were analyzed using the receiver-operating characteristic (ROC) curves, [†] $n = 83$, [‡] $n = 38$, [§] $n = 62$. AUC, area under the receiver characteristic curve.

Table 5 Data on factors associated with the risk of multiple falls in independent ambulatory subjects with spinal cord injury

Variable	Total [†] (n = 83)	Non-multiple fall [†] (n = 60)	multiple fall [†] (n = 23)	β Coefficient	SE	aOR [‡] (95% CI)	P value
Berg Balance Scale: ≥40 scores	43 (52)	28 (47)	15 (65)	1.02	0.59	2.77 (0.86–8.95)	0.089
Timed "Up & Go" Test: ≥26 s	33 (40)	19 (32)	14 (61)	0.76	0.58	2.14 (0.69–6.73)	0.190
10-Meter Walk Test: ≥10 s	31 (37)	18 (30)	13 (56)	0.71	0.61	2.03 (0.61–6.69)	0.246
Functional Reach Test: ≥20 cm	42 (51)	26 (43)	16 (70)	1.16	0.59	3.18 (1.01–10.03)	0.049*
Step test: ≤13 s	17 (45) [§]	12 (41) [§]	5 (56) [§]	1.52	1.03	4.61 (0.61–34.70)	0.137
Five Times Sit-to-Stand Test: ≤15 s	32 (52) [¶]	24 (52) [¶]	8 (50) [¶]	0.37	0.67	1.44 (0.38–5.41)	0.588

[†]The data are presented using n (%).

[‡]The data of each test were adjusted for the significant baseline characteristics including age, level and severity of SCI.

[§]Thirty-eight subjects could complete the test in which 29 subjects were non-multiple fallers and 9 subjects were multiple fallers.

[¶]Sixty-two subjects could complete the test in which 46 subjects were non-multiple fallers and 16 subjects were multiple fallers.

*aOR is significantly different from the reference group (P < 0.05).

SE, standard error; aOR, adjusted odds ratio; CI, confidence interval.

than 25 cm indicated risk of multiple falls in elderly (sensitivity = 63% and specificity = 59%). The different findings from this study may relate to characteristics of the subjects. Most of the subjects with SCI were males with an average age younger than those reported previously.^{10,17,23,24} Some studies have also suggested that patients with SCI are commonly active, have high levels of energy, and are enthusiastic.^{26,27} Such characteristics may drive the mobility of the subjects, particularly in those with good levels of functioning. Better levels of ability may also increase confidence while moving and enhance the integration of walking into daily activities, and thus these subjects have increased exposure to fall opportunities. The findings reflected those of Phonthee *et al.*² and Simpson *et al.*²⁸ who found that faller subjects with SCI and stroke had significantly better functional ability as determined using the TUG (P < 0.05). The researchers also hypothesized that increased level of ability was associated with increased exposure to fall opportunities for subjects with SCI and stroke.^{2,28}

Nowadays, rehabilitation programs are likely executed in the predictable, uncluttered and controlled environment of a rehabilitation room. The findings suggest that increased levels of ability increase risk of multiple falls for ambulatory subjects with SCI. Therefore, the data may emphasize the importance of functional integration in an actual environment to reduce risk of falls for these individuals. Nevertheless, there are some limitations of the findings. The study recruited subjects at a chronic stage of SCI in order to minimize functional alteration due to the effects of spontaneous recovery during the 6 months follow-up. However, this may limit the generalizability of the findings. Furthermore, the cut-off scores of the FRT had a moderate level of specificity (55%) which inferred that 45% of subjects who had an FRT of less than 20 cm still had a risk of multiple falls. The plausible explanation for the findings may be that a fall is a multi-causal event and that apart from intrinsic impairments, other extrinsic factors such as levels of physical activities, house modification and contextual conditions

Table 6 Inter-tester reliability of the six functional tests

Variable	ICCs	95% CI		SEM
		Lower	Upper	
Berg Balance Scale	0.998	0.996	0.999	0.66
Timed "Up & Go" Test	0.999	0.999	1.000	0.23
10-Meter Walk Test	0.997	0.993	0.998	0.20
Functional Reach Test	1.000	0.999	1.000	0.19
Step test	0.998	0.997	0.999	0.20
Five Times Sit-to-Stand Test	0.997	0.994	0.998	0.52

P value from the Intra-class Correlation Coefficients (ICCs (2,3)) <0.001 for every test.

CI, confidence interval; SEM, standard errors of measurement.

may influence the predictive ability of the tools. Currently, there is no reactive or anticipatory measure of postural control available, and that the FRT results may only be interpreted as a singular measure of postural control. Therefore, a further study that considers the effects of these factors and includes subjects at an early stage of SCI may thoroughly indicate the utility of the tools.

Conclusions

A fall is an important problem in ambulatory patients with SCI. The data suggest that the FRT (≥ 20 cm) may be used as a screening tool to predict risk of multiple falls in these individuals. The higher level of ability may increase exposure to fall opportunity, and thus indicates a higher risk of falls. However, with a moderate level of specificity, a further more comprehensive test may be required to clearly identify individuals at a risk of falls and subsequent injury.

Disclaimer statements

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Conflicts of interest None.

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