ORIGINAL ARTICLE

Failures on Obstacle Crossing Task in Independent Ambulatory Patients With Spinal Cord Injury and Associated Factors

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Abstract

Objectives: To primarily explore the proportion and factors relating to failure on an obstacle crossing task in ambulatory participants with incomplete spinal cord injury (iSCI); and to compare balance ability between participants who passed and failed on an obstacle crossing task.

Design: Cross-sectional design.

Setting: Tertiary rehabilitation center.

Participants: Independent ambulatory participants with an iSCI (N=113).

Interventions: Not applicable.

Main Outcome Measures: Primary outcomes were the ability to walk over small obstacles of sizes that are commonly found in homes and communities and factors relating to failure on an obstacle crossing task. The secondary outcome was the data from the timed Up and Go (TUG) test.

Results: Of the participants, 33 failed to walk over an obstacle. Using a walker significantly increased chance of failure, whereas having incomplete paraplegia and American Spinal Injury Association Impairment Scale grade D were the protective factors for the event ($P \leq .01$). The number of failures was also significantly increased because of leg contact with a wide or relative large obstacle (4 and 8cm, $P < .001$). Furthermore, participants who failed required significantly longer time to complete the TUG test than those who passed an obstacle crossing task ($P < .001$).

Conclusions: Apart from the ability of independent walking, rehabilitation professionals may need to emphasize the ability of movement modification of the lower extremities and balance control to improve safety issues for the patients.

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Approximately 70% of patients with incomplete spinal cord injury (iSCI) can become ambulatory after participation in a rehabilitation program.[1] However, most of them can walk nonfunctionally (ie, walk at a slow speed, walk only within the house, walk only a short distance, require assistance from persons or walking devices).[2,3] Amatachaya et al[4] report that 44% of independent ambulatory patients with iSCI fail to walk over small obstacles of sizes that are commonly found in homes and communities (<1−8cm). The inadequate clearance by both the limb and the walking device while walking over an obstacle can lead to a trip, fall, and subsequent injury. Previous studies indicate that 39% to 75% of independent ambulatory patients with iSCI have experienced at least 1 fall during a 6- to 12-month follow-up period, with most of the falls occurring as a result of stumbling over an obstacle while walking.[2,5,6]

To successfully walk over an obstacle, individuals need to alter their movement kinetics, kinematics, and spatiotemporal characteristics according to the size of obstacles on the floor; that is, increase their step length (for a wide obstacle) or use a flexor strategy to increase foot clearance (for a high obstacle) on a narrow base of support during a single-limb stance phase.[7,8-11] Therefore, the task is more challenging for ability of balance control and mobility than unobstructed walking.[7,8]

Amatachaya[4] found that walking with a walking device posed a risk of failure on an obstacle crossing task 8.5 times higher than not using a walking device (adjusted odds ratio=8.5, P=.07). Consequently, researchers suggest that gait safety of the patients may be threatened when facing obstacles in their environments after discharge. Nonetheless, the researchers recruited a small sample (n=34) and investigated only a few factors associated with failure on an obstacle crossing task, including walking device used and level and stage of spinal cord injury (SCI), without data on the functional impairments of individuals who passed and failed on an obstacle crossing task. As a result, the existing evidence may lack explanatory power to identify individuals with iSCI at a risk for falls. A study that included a larger sample size with the consideration of factors relating to baseline demographics, SCI characteristics, and balance impairments would offer useful information for clinicians to detect early and manage individuals at a risk of falls and subsequent injury after discharge. Therefore, this study primarily evaluated the proportion and factors relating to failure on obstacle crossing of independent ambulatory participants with iSCI, including baseline demographics (age, sex), SCI characteristics (cause, stage, severity, and level of SCI), and walking ability (walking with or without a walking device). Moreover, the study secondarily compared balance ability as measured using the timed Up and Go (TUG) test between participants who passed and failed on an obstacle crossing task. The researchers hypothesized that a large proportion of independent ambulatory participants with iSCI still had trouble walking over small obstacles, particularly those with severe SCI and a low level of walking ability (walking with a walking device). The researchers further hypothesized that participants who failed on an obstacle crossing task had greater balance impairments than those who successfully walked over an obstacle.

Methods

Participants

Participants were independent ambulatory patients with iSCI, aged ≥18 years, from a tertiary rehabilitation center in Thailand. Sample size calculation using the data of adjusted odds ratio of a previous study[4] indicated that the study required 30 to 375 participants. The inclusion criteria were ability to walk independently with or without a walking device for at least 15m (FIM locomotor scores 5–7).[12] The exclusion criteria were having an SCI from a progressive disease, any signs or symptoms that might affect the findings of the study, such as pain in the musculoskeletal system (at rest and with movement) with an intensity of pain of >5 (out of 10) on a numerical rating pain scale,[13] deformity of the spine (ie, scoliosis, kyphosis) and lower extremities (ie, genu recurvatum, genu varus) that could be visually detected, and other disorders that might have negative impacts on ambulatory ability. The experimental protocol of the study was approved by the Khon Kaen University Ethics Committee in Human Research. The eligible participants provided a written informed consent prior to participation in the study.

List of abbreviations:

AIS	American Spinal Injury Association Impairment Scale
iSCI	incomplete spinal cord injury
SCI	spinal cord injury
TUG	timed Up and Go

Apparatus

The study used 6 wooden obstacles (each of them 60cm long and 0.8cm thick) of 6 sizes, including 1cm wide, 4cm wide, 8cm wide, 1cm high, 4cm high, and 8cm high (fig 1), to represent the sizes of obstacles likely found in the home and community.[4,11]

Protocol of the study

Participants were interviewed and assessed for their baseline demographics and SCI characteristics, including cause of injury (traumatic or nontraumatic), stages of injury (subacute [postinjury time<12mo] or chronic [postinjury time≥12mo]),[14] severity of injury according to the criteria of the American Spinal Injury Association Impairment Scale (AIS) grades C or D,[15] level of injury (incomplete tetraplegia or incomplete paraplegia),[16] and baseline walking ability (ability to walk with or without a walking device).

After sufficient rest (blood pressure returned to a baseline level), participants were assessed for their ability to walk over the obstacles along a 10-m walkway in a random order (1 trial/size to minimize learning effects and simulate the condition during a fall, if any; total of 6 trials per participant). Prior to the test, the participants were instructed not to attempt any obstacle that may pose a risk of injury to them. The results were recorded as pass or fail. Pass referred to the ability to successfully complete the task by both the limb and an assistive device without any physical assistance or contacting the obstacle. Fail was recorded when the participants required assistance from the tester or contacted the obstacle with a limb or assistive device.[4,11]

Participants were also evaluated for their balance ability using the TUG test. The test measured the time required to complete the tasks of standing up from a standard armchair, walking at a fast and safe speed for 3m, turning around a traffic cone, walking back, and sitting down on the chair with or without a walking device. Then, the average time required over 3 trials was recorded.[17,18]

During the tests, participants did not wear shoes but wore an orthosis if normally used for daily walking and wore a lightweight safety belt around the waist with a therapist walking or being beside the participants to ensure safety. The sequences of the obstacle crossing test and TUG test were randomly ordered, with a sufficient period of rest between the tests and trials as required or with a Modified Borg Scale score >5 (range, 0–10; 0: no dyspnea; 10: worst possible dyspnea).

Statistical analyses

Descriptive statistics were used to explain baseline demographics, SCI characteristics, and findings of the study. Multiple logistic regression analyses were applied to determine the effects of independent variables, including baseline demographics, SCI characteristics, and baseline walking ability on the ability of walking over obstacles (pass or fail). The results were reported in terms of unadjusted and adjusted odds ratios with corresponding 95% confidence intervals. The findings of participants who passed and failed on an obstacle crossing task were compared using the independent samples t tests for continuous variables and chi-square test for categorical data. The level of statistical significance was set at $P<.05$.

Results

With the limited number of participants who were eligible based on the criteria of the study, the researchers recruited 113

Fig 1 Obstacles used and testing protocol. (A) Wooden obstacles of 6 sizes. (B) An obstacle crossing task (for 8-cm-high obstacle).

participants. However, only 94 participants could complete the TUG test because the test was used after the study had commenced. Most participants were men (n=74) at a chronic stage of SCI (n=82; average postinjury time, 44.54±43.91mo). Seventy participants walked with a walking device, including a standard walker, axillary crutches, and a standard single cane, and none of them used an orthosis (table 1).

Thirty-three participants (29%) who walked with a walking device failed to walk over an obstacle in at least 1 trial (range, 1−6 trials; total failures=88 trials) (see table 1 and fig 2). Most of them (n=26, 79%) failed while walking over an 8-cm-high and/or wide obstacle (see fig 2). Twenty-one participants (64%) had multiple failures (range, 2−6 trials; median failures=3 trials), and the rest of them failed on a trial in which 8 participants failed while walking over a 4- or 8-cm obstacle and the other 3 participants failed while walking over a 1-cm obstacle. All failures occurred because the leg (80 trials) or a standard walker (8 trials) contacted with the obstacle, and no participants failed because they required external assistance. Furthermore, participants who failed required a significantly longer time to complete the TUG test than those who passed the obstacle crossing test (P<.001) (see table 1).

The data of multiple logistic regression analysis demonstrated that failures on obstacle crossing were significantly associated with severity of SCI, level of injury, and using a standard walker (P≤.01) (table 2). Moreover, the number of failures was significantly related to leg contact, condition of the test (wide obstacle), and sizes of the obstacles (8cm high, 4cm wide, 8 cm wide; P≤.008) (table 3). The findings showed excellent power of the test for all variables (>90%), except using a walking device (standard walker or crutches, power of the test≤5%). This variable needed at least 844 participants to improve explanatory power of the findings.

Discussion

Falls are a major problem in ambulatory patients with SCI and frequently occur while walking, mostly because of stumbling over an obstacle.[2,5,6] Therefore, this study assessed the ability of walking over small obstacles of sizes commonly found in homes and communities (ie, uneven terrain, electric cords, tree branches) and the associated factors to provide data to identify early and manage those at risk of falls and subsequent injuries after discharge. Although a larger obstacle (>8cm) could be found at homes and communities, individuals with movement impairments may prefer to walk around them instead of attempting to negotiate the obstacle to avoid a possible risk of injury. The findings

Table 1 Baseline demographics and functional ability of the participants

Variable	Participants Who Passed (n=80)	Participants Who Failed (n=33)	P
Age (y)*	51.08 (47.91−54.26)	53.67 (46.77−60.56)	.965
Postinjury time (mo)*	44.28 (34.30−54.26)	55.38 (33.34−77.41)	.703
Sex: men[†]	55 (69)	19 (58)	.256
Using a walking device[†]			
No	43 (54)	0 (0)	<.001[‡]
Standard walker	24 (30)	28 (85)	NA
Axillary crutches	4 (5)	2 (6)	NA
Standard single cane	9 (11)	3 (9)	NA
TUG test (s)*	20.54 (17.04−24.05)	57.41 (38.61−76.21)	<.001[‡]

Abbreviation: NA, not applicable.

  * Data are presented using mean (95% confidence interval). The data between participants who passed and failed were compared using an independent sample t test.

  † Data are presented using n (%). The data between participants who passed and failed were compared using the chi-square test.
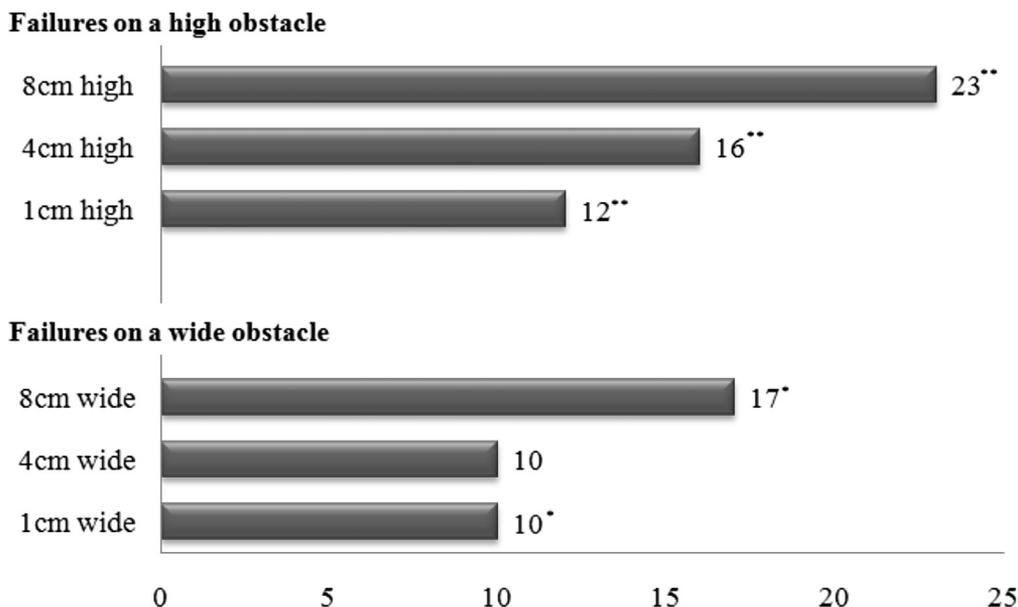
  ‡ Significant difference.

Failures on a high obstacle

Failures on a wide obstacle

Fig 2 Failures on obstacle crossing. *A condition with 1 trial of failure because of walking device contact. **A condition with 2 trials of failures because of walking device contact.

indicated that nearly one third of participants (29%) failed to walk over an obstacle in at least 1 trial. All of them walked with a walking device (see table 1), and 21 participants (64%) had multiple fails (range, 2−6 trials; median=3 trials), whereas the rest of them failed on a single trial mostly while walking over a relatively large obstacle (4 or 8cm).

The proportion of failures in the current study (29%) was lower than that reported previously (44%).[4] The differences may relate to the sample size and level of ability of the participants. Amatachaya[4] recruited 34 participants, and most of them (79%) walked with a walking device. The present study recruited 113 participants, and 62% of them used a walking device. A small number of participants may affect explanatory power of the findings. In addition, a higher proportion of participants who walked with a walking device may yield a greater rate of failures in the previous report[4] compared with that found in this study.

Findings of the current study clearly indicated that walking with a standard walker, having incomplete paraplegia, and having

an AIS grade D were significantly associated with the possibility of failures on an obstacle crossing task ($P \le .01$) (see table 2). Clinically, a standard walker is prescribed for a patient to compensate for significant weakness of the trunk and lower-extremity muscles, impaired balance control, and walking ability to promote levels of independence using contribution of the arms.[19,20] Consequently, these participants could walk independently overground without any disturbing factors. However, when encountering an obstacle on the floor, the participants may have difficulty modifying movements of the lower extremities to conform with the dimensions of the obstacle on the floor. Therefore, the possibility of failures of these participants was significantly increased compared with those who used a standard single cane ($P = .002$) (see table 2). The data from multiple logistic regression that the number of failures was significantly associated with leg contact, particularly when walking over a relatively large obstacle (4 or 8cm) (see table 3), also confirmed this assumption. Furthermore, the failures in participants who walked with a walker

Table 2 Factors associated with failures on an obstacle crossing (N=113)

Variable*	Total (n)	Pass (n=80)	Fail (n=33)	β Coefficient	SE	AOR (95% CI)	P
Cause of SCI: nontraumatic	72	52 (72)	20 (23)	0.94	0.73	0.39 (0.09−1.65)	.201
Stage of injury: chronic (PIT≥12mo)	82	59 (72)	23 (28)	0.55	0.64	0.57 (0.17−2.02)	.393
Severity of SCI: AIS grade D	95	75 (79)	20 (21)	2.13	0.79	0.11 (0.03−0.55)[†]	.007
Level of injury: incomplete paraplegia	75	60 (80)	15 (20)	1.81	0.70	0.16 (0.04−0.65)[†]	.010
Using a standard walker	52	24 (46)	28 (54)	2.35	0.77	10.48 (2.31−47.51)[†]	.002
Using axillary crutches	6	4 (67)	2 (33)	1.59	1.13	4.89 (0.53−44.89)	.160

NOTE. Data are presented as n (%) or as otherwise indicated.
Abbreviations: AOR, adjusted odds ratio; CI, confidence interval; PIT, postinjury time.
 * Variables are categorized as follows: cause of SCI: traumatic (reference group)/nontraumatic; stage of injury: subacute (PIT<12mo) (reference group)/chronic (PIT≥12mo); severity of SCI: AIS grade C (reference group)/AIS grade D; level of injury: incomplete tetraplegia (reference group)/incomplete paraplegia; using a standard walker: using a standard single cane (reference group)/using a standard walker; and using axillary crutches: using a standard single cane (reference group)/using axillary crutches.
 [†] AOR is significantly different from the reference group.

Table 3 Data relating to the number of failures of participants*

Variable[†]	Total[‡] (trials)	Pass[‡] (trials)	Fail[*,‡] (trials)	β Coefficient	SE	AOR (95% CI)	P
Cause of failures: leg contact	198	118 (60)	80 (40)	2.19	0.72	8.97 (2.17—37.03)[§]	.002
Condition of failures: wide obstacle	198	161 (81)	37 (19)	1.50	0.57	4.51 (1.49—13.69)[§]	.008
High obstacle[‖]							
4cm	198	182 (92)	16 (8)	0.20	0.50	0.82 (0.30—2.20)	.692
8cm	198	175 (88)	23 (12)	4.14	1.09	62.89 (7.56—523.09)[§]	<.001
Wide obstacle[‖]							
4cm	198	188 (95)	10 (5)	2.85	0.79	17.43 (3.71—81.93)[§]	<.001
8cm	198	181 (91)	17 (9)	20.23	0.66	6.13 (2.34—30.09)[§]	<.001

Abbreviations: AOR, adjusted odds ratio; CI, confidence interval.

 * Thirty-three participants failed, and each of them walked over 6 obstacles; therefore, there were 198 trials in total. Each of the 33 participants failed in 1 to 6 trials, with the total number of failures being 88 trials.

 † Variables are categorized as follows: cause of failures: device contact (reference group)/leg contact; condition of failures: high obstacle (reference group)/wide obstacle; size of high obstacle: 1cm (reference group)/4cm/8cm; and size of wide obstacle: 1cm (reference group)/4cm/8cm.

 ‡ Data are presented using the number of trials (%), and the findings on each variable were adjusted for the baseline characteristics, including stage of injury, severity of SCI, level of injury, and using a walking device.

 § AOR is significantly different from the reference group.

 ‖ High obstacle was placed vertically, whereas a wide obstacle was placed flat on the floor. Each obstacle was 60cm long and 0.8cm thick.

may correlate with the impairments of balance control that limit their ability to lift the device (standard walker) higher or place it further away to cover the size of the obstacle on the floor. Hence, some participants (n=8) failed as a result of a walker's contacting the obstacle. The differences of the TUG test data that are greater than the levels of the smallest real difference (10.8s)[21] may also confirm the clinically poorer dynamic balance ability and greater risk of falls of the participants who failed compared with those who passed an obstacle crossing task (see table 1).[22]

Incomplete paraplegia reflects the intact functions of the upper extremities; therefore, participants could use contribution of their arms to control movements while walking.[1] Having AIS grade D implied that the participants had mild sensorimotor impairments. Therefore, they had less limitations to control and modify movements according to the task demands than the participants with AIS grade C.[15] Consequently, having paraplegia and AIS grade D were the protective factors for the failures on an obstacle crossing task of the participants. ($P \leq .01$) (see table 2).

When adjusted for baseline data, the findings further indicated that the number of failures was significantly increased because of leg contact, particularly while walking over a wide and relatively large obstacle (4 or 8cm, $P<.001$) (see table 3). The findings may imply that the independent ambulatory participants still had a problem modifying movements of their legs, particularly when lengthening a step, even to cover a 4-cm-wide and 8-cm-wide obstacle. In addition, the significant increase in number of failures while walking over an 8-cm-high obstacle may suggest a difficulty of increasing flexor strategy in the participants.[7-11]

Findings of the current study provide clear evidence on the proportion and factors associated with failure on an obstacle crossing task. The findings suggest that, apart from ability of independent walking, therapists may need to emphasize ability of movement modification and balance control to minimize the risk of falls and the subsequent injuries that may occur to the patients.

Study limitations

There are some noteworthy limitations of the findings. First, the ability on obstacle crossing was measured with 1 trial/size to minimize learning effects and simulate the condition while fall

due to inability to successfully modify the movements while facing an obstacle. However, such a test may not capture the true capability of the participants when testing on different occasions or when repeated several times. Nonetheless, most participants who failed (79%) had a problem on multiple trials, and for those who failed on a single trial, most of them (8 of 12 participants) had a problem while walking over a relatively large obstacle (4 or 8cm). This may partially ensure the reliability and validity of the major outcome of the study (failures on obstacle crossing). Second, the researchers did not collect data for time of using a walking device and routine training programs. However, all participants were cross-sectionally recruited from the same rehabilitation center. They were trained to use their walking device properly and could walk independently without external assistance for at least 15m. These may minimize effects of different routine training and unfamiliarity with the walking device on the outcomes. Third, the kinematic and kinetic data while walking over an obstacle were derived from data in other populations who did not use a walker (ie, healthy participants, patients with stroke).[7-11] Furthermore, with a limited number of eligible participants, this study recruited 113 participants with only a small number of those who used axillary crutches and a standard single cane. This affected explanatory power of the findings for the walking device used ($\leq$5%), and the data indicated that this variable needs at least 844 participants to improve power of the findings. Finally, the tests on an obstacle crossing were executed in a closed, predictable environment of a rehabilitation room, and participants were aware of the position of the obstacles on the floor. Such conditions may not truly simulate conditions of falls after discharge. A further study of a larger number of participants that investigates effects of these variables with prospective exploration of the relation between failures on an obstacle crossing task and falls may fulfill the findings in this area.

Conclusions

Approximately one third of independent ambulatory participants with iSCI failed on an obstacle crossing task. Using a standard walker significantly increased the possibility of failure on the task, whereas having incomplete paraplegia and AIS grade D were the

protective factors for the event. The number of failures was also significantly increased because of leg contact and a wide and relatively large obstacle. Participants who failed also showed greater impairments of balance control than those who successfully walked over an obstacle. Therefore, apart from ability of independent walking, rehabilitation strategies are needed to emphasize the ability of the lower limbs and balance control of the participants, particularly those who walk with a standard walker. In addition, the incorporation of obstacles of varying widths and heights in walking training would help patients to successfully manage hazardous environments or make them aware that they are at risk of injury and need an alternative strategy (ie, walking around obstacles instead of attempting to walk over them after discharge).

Keywords

Balance; Paraplegia; Physical therapy; Rehabilitation; Tetraplegia; Walking

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