Research Paper

Hong Kong Physiotherapy Journal
Vol. 41, No. 1 (2021) 55–63
DOI: 10.1142/S1013702521500050

Hong Kong Physiotherapy Journal
https://www.worldscientific.com/worldscinet/hkpj

The utility of upper limb loading device in determining optimal walking ability in ambulatory individuals with spinal cord injury

Makamas Kumprou[1,2], Pipatana Amatachaya[2,3,*,‡], Thanat Sooknuan[2,4], Preeda Arayawichanon[2,5], Thiwabhorn Thaweewannakij[1,2] and Sugalya Amatachaya[1,2,†,‡]

[1]*School of Physical Therapy, Faculty of Associated Medical Sciences Khon Kaen University, Khon Kaen 40002, Thailand*

[2]*Improvement of Physical Performance and Quality of Life (IPQ) Research Group Khon Kaen University, Khon Kaen 40002, Thailand*

[3]*School of Mechanical Engineering, Faculty of Engineering and Architecture Rajamangala University of Technology Isan Nakhon Ratchasima 30000, Thailand*

[4]*Department of Electronics Engineering Faculty of Engineering and Architecture Rajamangala University of Technology Isan Nakhon Ratchasima 30000, Thailand*

[5]*Department of Rehabilitation Medicine, Faculty of Medicine Khon Kaen University, Khon Kaen 40002, Thailand*

*pipatana.am@rmuti.ac.th
†samata@kku.ac.th

Received 29 March 2020; Accepted 11 December 2020; Published 18 January 2021

Background: Walking devices are frequently prescribed for many individuals, including those with spinal cord injury (SCI), to promote their independence. However, without proper screening and follow-up care, the

‡Corresponding authors.

individuals may continue using the same device when their conditions have progressed, that may possibly worsen their walking ability.

Objective: This study developed an upper limb loading device (ULLD), and assessed the possibility of using the tool to determine the optimal walking ability of ambulatory participants with SCI who used a walking device daily ($n = 49$).

Methods: All participants were assessed for their optimal walking ability, i.e., the ability of walking with the least support device or no device as they could do safely and confidently. The participants were also assessed for their amount of weight-bearing on the upper limbs or upper limb loading while walking, amount of weight-bearing on the lower limbs or lower limb loading while stepping of the other leg, and walking performance.

Results: The findings indicated that approximately one third of the participants (31%) could progress their walking ability from their current ability, whereby four participants could even walk without a walking device. The amount of upper limb loading while walking, lower limb loading ability, and walking performance were significantly different among the groups of optimal walking ability ($p < 0.05$). Furthermore, the amount of upper limb loading showed negative correlation to the amount of lower limb loading and walking performance ($\rho = -0.351$ to -0.493, $p < 0.05$).

Conclusion: The findings suggest the potential benefit of using the upper limb loading device and the amount of upper limb loading for walking device prescription, and monitoring the change of walking ability among ambulatory individuals with SCI.

Keywords: Weight-bearing; walker; crutches; walking; rehabilitation; physical therapy.

Introduction

A walking device is commonly prescribed to many individuals, including those with spinal cord injury (SCI), to allow various degrees of upper limb contribution to compensate for the lower limb and mobility deficits, and to promote the independence and effects of task-specific walking practice for these individuals.[1,2] Therefore, individuals who use different types of walking devices should have different weight-bearing or lower limb loading abilities, and different requirements for upper limb contribution while walking.[2–4] Then, when their lower limb loading ability is improved, individuals could reduce the need for upper limb involvement and progress their walking performance.[2,5,6]

The reduction of upper limb contribution when the individuals could walk safely, allows for a less cumbersome, reciprocal, and efficient walking manner,[2–4] as well as minimizes the possible negative impacts due to long-term use of a walking device (e.g., the development of abnormal walking manners with high attention and metabolic demands, as well as the risk of musculoskeletal injuries in the upper extremities and back).[7–12] Contrarily, early reduction of the upper limb contribution when individuals are unable to do so could destroy the self-confidence and safety of individuals that could affect their independence.[13] Therefore, the ability to determine the walking alteration requires periodic follow-up from an experienced health professional over time. Nevertheless, such follow-up by the same assessor may not be possible in every healthcare setting, especially in those cases with limited number of staff, that could affect data comparison among the assessors, as well as time intervals.[4,14–16] These problems may result in many ambulatory individuals with SCI lacking periodic follow-up for walking alteration, causing them to continue using the same walking device even when their walking ability has already progressed or deteriorated.[1,6,13] This issue is important nowadays given that the present rehabilitation lengths have dramatically decreased,[17] and that many ambulatory individuals with SCI need a walking device, particularly a standard walker, at the time of discharge to promote their independence, and minimize the burden of care on family members.[1,3] The researchers hypothesized that the development of an upper limb loading device (ULLD) to assess the amount of weight-bearing on the upper limbs or upper limb loading during walking may indirectly reflect the lower limb loading ability and walking performance of ambulatory individuals with SCI. Thus, this study developed a ULLD from an adjustable walker and used the tool to measure the amount of upper limb loading while the participants were walking. Then the study compared the amount of upper limb loading, lower limb loading ability, and walking performance among the groups of ambulatory individuals with SCI who walked at their optimal ability. Furthermore, the study explored the correlation between the amount of upper limb loading, lower limb loading ability, and walking performance in ambulatory individuals with SCI. The findings would suggest the use of upper limb loading and a ULLD as an alternative measure to prescribe a walking device and monitor the change of walking ability of individuals who used a walking device in various settings (i.e., hospital, clinic, community, or patient's home).

Materials and Methods

Participants

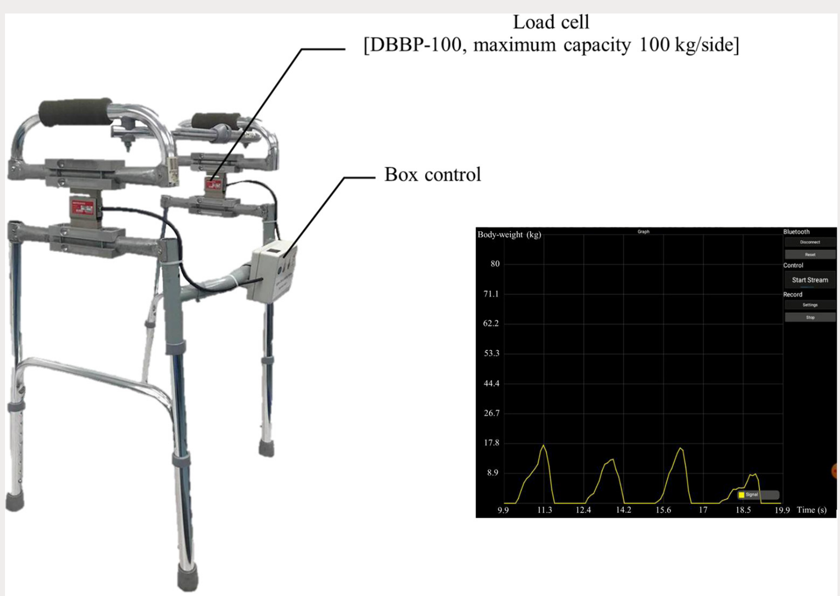
This study cross-sectionally recruited community-dwelling ambulatory individuals with SCI who walked independently with a walking device from June 2018 to August 2019. The inclusion criteria were as follows: at least 18 years of age, having SCI from traumatic and non-progressive causes, and experiencing a subacute and chronic stage of injury.[1,18] Individuals were excluded if they had any signs and symptoms that might affect the outcomes — for example, deformity in the joints of the extremities, leg length discrepancy, and pain in the musculoskeletal system with a pain score of more than 5 out of 10 on a visual analog scale.[1,6] From the sample size calculation for a correlation study with the alpha level set at 0.05, power of test at 0.8, and level of correlation at 0.55 (from a pilot study, $n = 15$), the findings indicated that the study needed at least 40 participants. Every participant signed informed consent, which was approved by the local Ethics Committee for Human Research (HE601164) prior to participation in the study.

Research procedure

The research protocol was divided into two phases, including upper limb loading device development and data collection. Details of each phase are provided in the following.

Phase I: Upper limb loading device development

The ULLD was developed from an adjustable walker and the digital load cells [model: DBBP-100; maximum capacity: 100 kg/side; mini-patent application number: 2003003449; see Fig. 1(a)] to properly quantify the amount of upper limb loading during walking as controlled by a mobile application. Subsequently, the tool was calibrated using a standard calibration system based on the United Kingdom Accreditation Service (UKAS M3003, edition 3: 2019, with an accuracy of up to 0.2 kg and an uncertainty of measurement of ±0.2 kg). After development, the tool could generate the amount of upper limb loading in real-time while an individual was walking [Fig. 1(b)] and the



(a) (b)

Fig. 1. (a) An upper limb loading device and (b) its real-time display section from mobile application (mini-patent application number: 2003003449).

data was automatically saved in digital memory as an Excel file for further analysis. Then the researchers used the tool to assess the amount of upper limb loading of the participants.

Phase II: Data collection

The eligible participants were interviewed and assessed for their demographics and SCI characteristics, including gender, age, cause of injury, post-injury time, level and severity of SCI, using sensorimotor scores and criteria from the American Spinal Cord Injury Association Impairment Scale (AIS), and the type of walking device used in their daily walking. Subsequently, participants were assessed for the amount of upper limb loading while walking, lower limb loading ability while stepping of the other leg, and walking performance using the 10-m walk test (10MWT) and the 6-min walk test (6MinWT) in a random order. Details of the tests are as follows.

Upper limb loading while walking. The participants walked along a 10-m walkway with a ULLD at their preferred speed. Their amount of upper limb loading throughout the walkway was automatically saved in digital memory, and the average upper limb loading along the walkway was reported in terms of the percentage of body weight.

Lower limb loading ability. Participants were assessed for their weight-bearing ability on the lower limbs or lower limb loading ability during a single limb support period while stepping with the other leg. Participants stood in a step-standing position and placed the leg being tested on a digital load cell (model: L6E3-C, 200 kg-3G; maximum capacity 200 kg with an accuracy of 0.035 kg).[19] They were instructed to shift their body weight onto the leg being tested as much as possible and step forward with the other leg with or without using their arms, according to their ability. Participants performed five trials for each lower extremity in which the first two trials served as practice trials, and the average lower limb loading ability over the other three trials of each lower limb was reported as a percentage of body weight.[20]

Optimal walking ability. Previous studies[2–4] reported the levels of body weight support by different types of walking devices, i.e., up to 75–100% of body weight for a standard walker, up to 50% of body weight for crutches, and only 15–20% of body weight for a single cane. Therefore, participants who had lower limb loading ability better than their usual ability were asked to gradually change a walking device to the ones with the least support or no device as they could walk safely and confidently as determined using the opinion of an experienced physical therapist. The findings were used to indicate an optimal walking ability of the participants.[6]

The 10-m walk test. The 10MWT measures an ambulatory status of the participants in terms of walking speed. Outcomes of the test are associated with overall quality of gait and community participation of the individuals.[21] Participants walked at their optimal ability (with or without a walking device) at a preferred walking speed along a 10-m walkway. The time required for over 4 m in the middle of the walkway was recorded in order to minimize acceleration and deceleration effects. The average finding over the three trials was used for data analysis.[22,23]

The 6-min walk test. The test measures the functional endurance of ambulatory individuals with SCI.[24] Participants walked along a rectangular walkway at their optimal ability (with or without a walking device) for as long as possible in 6 min. During the test, participants were allowed to rest as needed and continue walking as soon as they could, without stopping the timer. Every minute during the test, participants were informed about the time left and offered encouragement. The distance covered after 6 min was recorded.[24,25]

Data analysis

Participants were arranged into the groups of optimal walking ability. With non-normal data distribution, descriptive statistics [median and interquartile range (IQR)] were used to explain the demographics, SCI characteristics, and the findings of the study. The Kruskal–Wallis test or Chi-square test was applied to compare the findings among the groups for continuous and categorical data, respectively. Then the Mann–Whitney U-test was applied to analyze the differences for every pairwise comparison. Furthermore, Spearman's rank correlation coefficient was applied to quantify the relationship between the amount of upper limb loading and other variables relating to walking performance of the participants. A p-value less than 0.05 was considered statistically significant.

Results

Forty-nine ambulatory participants with SCI who daily walked with a walking device completed this

Table 1. Demographics and SCI characteristics of participants.

Variable	All participants ($n = 49$)*	Groups of optimal walking ability: Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	None ($n = 4$)	p-Value
Age (year), median (IQR)	58 (48.50–64.50)	65.50 (51–69.75)	54 (40.75–58.75)	60 (45–63)	58.50 (54–66.75)	0.088^{b}
Post-injury time (months), median (IQR)	61 (25–120)	96 (46–150)	78 (24–160.25)	53 (26–108)	18 (11.25–58.50)	0.099^{b}
Stage of injury: Chronic,[a] n(%)	45(91.8)	12(100)	12(85.7)	18(94.7)	3(75)	0.322^{c}
Gender: Male,[a] n(%)	34(69.4)	9(75)	8(57.1)	16(84.2)	1(25)	0.077^{c}
Cause: Traumatic,[a] n(%)	21(42.9)	6(50)	6(42.9)	8(42.1)	1(25)	0.855^{c}
Level of injury: Paraplegia,[a] n(%)	30(61.2)	6(50)	10(71.4)	12(63.2)	2(50)	0.684^{c}
Severity of injury, n (%):						
AIS C	9(18.4)	2(16.7)	4(28.6)	3(15.8)	—	0.577^{c}
AIS D	40(81.6)	10(83.3)	10(71.4)	16(84.2)	4(100)	
FIM-L, n(%):						
FIM-L 5	6(12.2)	2(16.7)	3(21.4)	1(5.3)	—	0.434
FIM-L 6	43(87.8)	10(83.3)	11(78.6)	18(94.7)	4(100)	

Notes: IQR: Interquartile range, AIS: American Spinal Cord Injury Association impairment scale, and FIM-L: Functional Independence Measure Locomotor. *Prior to the assessments, most participants used a standard walker ($n = 23$, 47%), followed by a single cane ($n = 17$, 35%) and the crutches ($n = 9$, 18%); [a]these variables were categorized according to the following criteria: stage of injury: subacute/chronic, gender: male/female, cause of injury: traumatic/non-traumatic SCI, and level of injury: incomplete tetraplegia/incomplete paraplegia. [b]p-Value was from Kruskal–Wallis test. [c]p-Value was from Chi-square test.

study. Most participants were males with a median age of 58 years, at a chronic stage (with a median post-injury time of 61 months), had mild lesion severity (AIS D, 82%), and could walk over a long distance (more than 50 m) with walking device (88%; Table 1).

In their daily walking, most participants ($n = 23$, 47%) used a standard walker, followed by a single cane ($n = 17$, 35%) and the crutches ($n = 9$, 18%). After assessments of their optimal walking ability, it was found that most participants could walk with a single cane ($n = 19$, 39%),

Table 2. Sensorimotor scores of the participants.

Variable	All participants ($n = 49$)	Groups of optimal walking ability: Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	No ($n = 4$)	p-Value
Motor scores						
Upper extremities (50 scores)	50 (44.50–50)	47.50 (38.75–50)	50 (50–50)	50 (45–50)	49 (41.25–50)	0.222
Lower extremities (50 scores)	35 (25.50–42)	35 (25.25–41.75)	30 (24–37.50)	37 (27–43)	41 (34.75–45)	0.150
Sensory scores						
Light-touch Upper extremities (76 scores)	76 (72–76)	74 (60.50–76)	76 (75–76)	76 (76–76)	71 (50.25–76)	0.168
Lower extremities (36 scores)	22 (18–30.50)	19 (18–23.50)	22 (19.50–32.25)	26 (18–35)	22 (18–32)	0.243
Pinprick Upper extremities (76 scores)	76 (72–76)	74 (60–76)	76 (72–76)	76 (76–76)	71 (50.25–76)	0.121
Lower extremities (36 scores)	24 (18–32)	22 (18–24)	21 (18–31.50)	26 (18–35)	22 (18–32)	0.400

Note: The data were presented using median and IQR, according to the American Spinal Cord Injury Association protocol. The p-value was from Kruskal–Wallis test.

Table 3. The upper limb loading while walking, lower limb loading ability during stepping of the other leg, and walking performance tests of the participants.

Variable	All participants ($n = 49$)	Groups of optimal walking ability: Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	No ($n = 4$)	p-Value
Loading ability (% of body weight)						
Upper limb loading	22.44 (14.32–30.62)	31.26 (22.85–42.79)	24.63 (15.06–32.35)	18.80^{W} (5.83–28.23)	$10.05^{W,Cr}$ (2.15–14.99)	0.002*
LLLA of the more-affected leg	83.24 (77.76–85.28)	78.72 (70.32–81.07)	85.42 (65.58–90.72)	90.16^{W} (84.65–94.12)	92.33^{W} (87.24–96.77)	0.001*
LLLA of the less-affected leg	84.72 (77.56–91.78)	77.28 (70.55–85.55)	88.07 (71.15–91.24)	89.24^{W} (85.74–91.98)	95.21 (77.98–99.28)	0.029*
Walking performance tests						
The 10-m walk test (m/s)	0.49 (0.29–0.73)	0.29 (0.22–0.42)	0.32 (0.27–0.53)	$0.70^{W,Cr}$ (0.50–0.86)	$0.69^{W,Cr}$ (0.59–0.91)	< 0.001*
The 6-min walk test (m)	118.22 (75.56–142.80)	77.31 (62.98–118.48)	97.05 (69.75–153.25)	130.20^{W} (112–191.80)	$182.55^{W,Cr}$ (153.60–216.68)	0.003*

Notes: LLLA: Lower limb loading ability. The data are median and IQR. The superscripts designate the group(s) with significant differences from the indicated group; here, W denotes walker and Cr denotes the Crutches. The p-value is from Kruskal–Wallis test, and *indicates significant difference. Pairwise differences were compared using the Mann–Whitney U-test.

Table 4. Relationship between the amount of upper limb loading, lower limb loading ability, and walking performance tests.

Variable ($n = 49$)	ρ	p-Value
Lower limb loading ability during stepping of the other leg		
Data of the more-affected side	−0.420	0.003*
Data of the less-affected side	−0.449	0.001*
Walking tests		
The 10-m walk test	−0.351	0.013*
The 6-min walk test	−0.493	< 0.001*

Note: Here, ρ is Spearman's rank correlation coefficient between the amount of upper limb loading during walking and other variables. Also, *indicates significant difference.

followed by the crutches ($n = 14$, 29%) and a standard walker ($n = 12$, 24%); four participants (8%) were able to walk without a walking device (Table 1). The demographics, SCI characteristics, and sensorimotor scores showed no significant differences among the groups of optimal walking ability ($p > 0.05$; Tables 1 and 2). Nevertheless, there were significant differences among the groups for the amount of upper limb loading while walking, lower limb loading ability during stepping of the other leg, and walking performance as determined using 10MWT and 6MinWT, particularly in those who walked with a single cane and no walking device compared to those who needed a standard walker and the crutches ($p < 0.05$; Table 3). Furthermore, the amount of upper limb loading was negatively correlated to lower limb loading ability and the outcomes of 10MWT and 6MinWT ($\rho = -0.351$–-0.493, $p < 0.05$; Table 4).

Discussion

With lower limb and mobility deficits, many ambulatory individuals with SCI need a walking device for their daily walking.[1,6] However, our findings illustrated that approximately one third of participants (31%) could progress their walking ability, whereby some were even able to walk without a walking device (Table 1). The findings also indicated significant differences in upper limb loading, lower limb loading ability, and walking performance among the groups of optimal walking ability, i.e., ability of walking with the least support or no device safely and confidently ($p < 0.05$; Table 3). Moreover, the amount of upper limb loading negatively correlated to the lower limb loading and walking performance of the participants ($\rho = -0.351$–-0.493; Table 4).

The findings were consistent with previous reports that many ambulatory individuals with SCI walked daily using a standard walker.[1,6,20] However, after assessment of the optimal walking ability, the majority of participants required a single cane (39%), followed by the crutches (29%) and a standard walker (24%); four participants were able to walk without a walking device (8%; Table 1). This evidence was associated with the data reported from a developed country[26] wherein most ambulatory individuals with SCI used cane and crutches, while only a few participants used a standard walker. Although walking with a high-support walking device promotes safety and confidence for the individuals through upper limb involvement, such walking manners require high attention[7] and metabolic demands,[8,9] limit limb movements,[10] introduce abnormal walking manners,[11] and also enhance the risk of musculoskeletal problems in the upper extremities and back.[12] Therefore, a strategy to promote walking ability, i.e., minimizing use of the upper extremities while walking, is needed.

The findings further suggest that participants who could walk optimally with different types of walking device or without a walking device had different lower limb loading abilities and walking performances, and thus they required different amounts of upper limb loading while walking ($p < 0.05$; Table 3). Those who could walk optimally with a single cane and without a walking device needed an amount of upper limb loading less than 19% of their body weight (Table 3), which was clearly less than those needed for the ones who required standard walker and crutches (approximately 31% and 25% of their body weights, respectively; $p < 0.01$; Table 3). These findings are associated with the lower limb loading ability data that individuals who required a single cane and no walking device had a lower limb loading ability of more than 90% of their body weight (Table 3), whereas those who needed standard walker and crutches had the lower limb loading abilities of 78–79% and 85–88% of their body weights, respectively. The findings were associated with previous reports[2,3] that a single cane can support only 15–20% of the individual's body weight. Therefore, it is used in those with relatively good walking ability to enhance the body base of support, self-confidence, and tactile information during walking.[2,3] Our findings further indicated that individuals who could optimally walk with a single cane and no device were able to walk faster than 0.67 m/s, which was suggested as a threshold for the ability of walking without a walking device[27] and functional walking (faster than 0.6 m/s).[1] Having good lower limb loading ability also resulted in these individuals using their energy efficiently[8,9]; thus, they could complete a significantly longer distance walk in 6 min than those who needed walker and crutches ($p < 0.01$; Table 3).

Furthermore, the upper limb contribution while walking was negatively correlated to the lower limb loading ability and walking performance (i.e., a reduction in the amount of upper limb loading associated with the increased lower limb loading ability, walking speed, and distance covered in 6 min; $\rho = -0.351$–-0.493; Table 4). Previous studies also reported that walking with high supportive demand from the upper extremities could confound the lower limb functions, make walking cumbersome, and increase the energy expenditure that could affect walking speed and distance covered.[1,20,22,27] Thus, our findings suggested that walking devices should be prescribed to those who actually need them, along with a periodic follow-up to monitor their walking alteration over time in order to optimize their walking performance and minimize possible negative impacts that could occur due to long-lasting use of a walking device. Hicks *et al.*[28] also reported that an improved walking ability is associated with increased life satisfaction and physical functioning of the individuals. Our findings also suggest the use of a ULLD and the upper limb loading as an alternative measure for determining and the periodic follow-up of optimal walking ability of ambulatory individuals with SCI in various clinical and home-based settings.

Nevertheless, there are some limitations of the study. With the major aim to capture those with the potential of walking progression, the study recruited only those who could walk independently with a walking device. Such criteria resulted in most participants requiring rather low amounts of upper limb loading while walking (Table 3), including those who used a standard walker, and no clear differences between those who used a standard walker and the crutches ($p > 0.05$; Table 3). In addition, the cross-sectional data cannot clearly confirm the proportion of actual progression, benefits, and possible negative impacts after walking progression, as well as the causal relationship between upper limb loading, lower limb loading, and walking performance of the participants. Therefore, a further prospective study with participants having a wider range of walking abilities and data analysis on a cut-off score for optimal walking ability specifically for individuals with SCI is needed. In addition, information on how ULLD facilitated the therapist to make the decision and the agreement between patients classified solely based on various ULL cut-offs versus the patients classified with therapist decision are also worthy to be investigated.

Conflict of Interest

The authors declare no conflict of interest.

Funding/Support

The researchers sincerely thank the Research and Researcher for Industry (RRi) (PHD60I0027), Postgraduate School, and Research and Graduate Studies, Khon Kaen University, Thailand, for the funding support.

Author Contributions

Concept and design, interpretation of the data, critical revision of the paper for important intellectual content, final approval of the paper, provision of study materials and patients, and obtaining of funding, administrative, and technical support were made by Sugalya Amatachaya. Makamas Kumprou was involved in the concept and design, collection and assembling of data, analysis and interpretation of the data, drafting of the paper, and final approval of the paper. Pipatana Amatachaya helped in the concept and design, critical revision of the paper for important intellectual content, provision of study materials, obtaining of funding, providing administrative, logistic, and technical support, and the final approval of the paper. Thanat Sooknuan also helped in the concept and design, provision of study materials, providing technical support, and the final approval of the paper. Preeda Arayawichanon took part in the concept and design, provision of study patients, providing administrative support, critical revision of the paper for important intellectual content, and the final approval of the paper. Finally, Thiwabhorn Thaweewannakij contributed to the concept and design, provision of study patients, providing administrative support, critical revision of the paper for important intellectual content, and the final approval of the paper.

References

1. Saensook W, Phonthee S, Srisim K, Mato L, Wattanapan P, Amatachaya S. Ambulatory assistive devices and walking performance in patients with incomplete spinal cord injury. Spinal Cord 2014; 52(3):216–9.
2. Melis EH, Torres-Moreno R, Barbeau H, Lemaire ED. Analysis of assisted-gait characteristics in persons with incomplete spinal cord injury. Spinal Cord 1999; 37(6):430–9.
3. Bateni H, Maki BE. Assistive devices for balance and mobility: benefits, demands, and adverse consequences. Arch Phys Med Rehabil 2005; 86(1): 134–45.
4. Haubert LL, Gutierrez DD, Newsam CJ, Gronley JK, Mulroy SJ, Perry J. A comparison of shoulder joint forces during ambulation with crutches versus a walker in persons with incomplete spinal cord injury. Arch Phys Med Rehabil 2006; 87(1):63–70.
5. Water RL, Adkins R, Yakura J, Vigil D. Prediction of ambulatory performance based on motor scores derived from standards of the American Spinal Injury Association. Arch Phys Med Rehabil 1994; 75(7):756–60.
6. Khuna L, Mato L, Amatachaya P, Thaweewannakij T, Amatachaya S. Increased lower limb loading during sit-to-stand is important for the potential for walking progression in ambulatory individuals with spinal cord injury. Malays J Med Sci. 2019; 26(1):99–106.
7. Wright DL, Kemp TL. The dual-task methodology and assessing the attentional demands of ambulation with walking devices. Phys Ther 1992; 72(4): 306–12.
8. Potter BE, Wallace WA. Everyday aids and appliances. BMJ 1990; 301(3):1037–9.
9. Adedoyin RA, Opayinka AJ, Oladokun ZO. Energy expenditure of stair climbing with elbow and axillary crutches. J Physiother 2001; 88(1):47–51.
10. Bateni H, Heung E, Zettel J, McIlroy WE, Maki BE. Can use of walkers or canes impede lateral compensatory stepping movements? Gait Posture 2004; 20(1):74–83.
11. Behrman AL, Bowden MG, Nair PM. Neuroplasticity after spinal cord injury and training: An emerging paradigm shift in rehabilitation and walking recovery. Phys Ther 2006; 86(10):1406–25.
12. Jain NB, Higgins LD, Katz JN, Garshick E. Association of shoulder pain with the use of mobility devices in persons with chronic spinal cord injury. PMR 2010; 2(10):896–900.

13. Kim MO, Burns AS, Ditunno Jr JF, Marino RJ. The assessment of walking capacity using the walking index for spinal cord injury: self-selected versus maximal levels. Arch Phys Med Rehabil 2007; 88(6): 762–7.
14. Raaben M, Holtslag HR, Augustine R, Merkerk RO, Koopman BFJM, Blokhuis TJ. Technical aspects and validation of a new biofeedback system for measuring lower limb loading in dynamic situation. Sensors (Basel) 2017; 17(3): 658:1–658:10.
15. Rogers E. Analysis of force distribution on upper body limbs during ambulation with crutches. Master's thesis. Toronto: University of Toronto, 2014:1–79.
16. van Hedel HJ, Wirz M, Dietz V. Assessing walking ability in subjects with spinal cord injury: Validity and reliability of 3 walking tests. Arch Phys Med Rehabil 2005; 86(2):190–6.
17. National SCI Statistical Center. Spinal cord injury facts and figures at a glance. 2019. Available at: https://www.nscisc.uab.edu/Public/Facts%20and%20Figures%202019%20-%20Final.pdf [accessed October 10, 2019].
18. Jørgensen V, Forslund EB, Opheim A, Wahman K, Hulting C, Seiger A, et al. Falls and fear of falling predict future falls and related injuries in ambulatory people with spinal cord injury: A longitudinal observation study. J Physiother 2017; 63(2):108–13.
19. Phonthee S, Amatachaya P, Sooknuan T, Amatachaya S. Lower limb support ability during stepping activity and its importance in ambulatory individuals with stroke. Int Disabil Hum Dev 2019; 18(2):1–10.
20. Kumprou M, Amatachaya P, Sooknuan T, Thaweewannakij T, Amatachaya S. Is walking symmetry important for ambulatory patients with spinal cord injury? Disabil Rehabil 2017; 40(7):836–41.
21. Lapointe R, Lajoie Y, Serresse O, Barbeau H. Functional community ambulation requirements in incomplete spinal cord injured subjects. Spinal Cord 2001; 39(6):327–35.
22. Saensook W, Poncumhak P, Saengsuwan J, Mato L, Kamruecha W, Amatachaya S. Discriminative ability of the three functional tests in independent ambulatory patients with spinal cord injury who walked with and without ambulatory assistive devices. J Spinal Cord Med 2013; 37(2):212–7, doi: 10.1179/2045772313Y.0000000139.
23. Jackson AB, Carnel CT, Ditunno JF, Read MS, Boninger ML, Schmeler MR, et al. Outcome measures for gait and ambulation in the spinal cord injury population. J Spinal Cord Med 2008; 31(5):487–99.
24. Poncumhak P, Saengsuwan J, Kamruecha W, Amatachaya S. Reliability and validity of three functional tests in ambulatory patients with spinal cord injury. Spinal Cord 2013; 51(3):214–7.
25. Phonthee S, Saengsuwan J, Siritaratiwat W, Amatachaya S. Incidence and factors associated with falls in independent ambulatory individuals with spinal cord injury: A 6-month prospective study. Phys Ther 2013; 93(8):1061–72.
26. Biering-Sørensen F, Hansen RB, Biering-Sørensen J. Mobility aids and transport possibilities 10–45 years after spinal cord injury. Spinal Cord 2004; 42 (12):699–706.
27. Poncumhak P, Saengsuwan J, Amatachaya S. Ability of walking without a walking device in patients with spinal cord injury as determined using data from functional tests. J Spinal Cord Med 2014; 37(4):389–96.
28. Hicks AL, Adams MM, Ginis KM, Giangregorio L, Latimer A, Phillips SM, et al. Long-term body-weight-supported treadmill training and subsequent follow up in persons with chronic SCI: Effects on functional walking ability and measures of subjective well-being. Spinal Cord 2005; 43(5):291–8.