www.nature.com/sc

ISCoS The International Spinal Cord Society

ARTICLE

Check for updates

Orthotic walking outcome of persons with motor complete low thoracic spinal cord injury—a retrospective study

Thangavelu Senthilvelkumar [1] ✉, Prashanth H. Chalageri [1], Samuel Kirubakaran Durairaj [1], Maheswari Venkatraman [1], Bobeena Rachel Chandy [1], Grace Rebekah [2], Raji Thomas [1] and Jacob George [1]

STUDY DESIGN: Retrospective study.
OBJECTIVE: To analyse the orthotic walking outcome of patients with Low Thoracic Spinal Cord Injury (LT-SCI).
SETTING: The Rehabilitation Institute at Christian Medical College, Vellore, India.
METHODS: Data between January 2005 and June 2015 were retrospectively collected from electronic medical reports of patients with motor complete LT- SCI who were admitted for the comprehensive rehabilitation program. The orthotic walking outcome of these patients was measured by the Walking index for SCI version II (WISCI II). Demographical and clinical parameters were measured and their association with the walking outcome was analyzed using regression analysis.
RESULTS: A total of 430 patients were identified within the study period. Eighty-five percent of people ($n = 365$) achieved walking at the time of discharge (WISCI II level 12 = 260 and level 9 = 105). Out of 11 demographical and clinical parameters considered, eight of them were found to be significant predictors of walking in the univariate analysis. Age less than 30 years had the highest odds of predicting WISCI II level 9 and level 12 than those older in the multivariate analysis (OR 17.58; 95% CI 7.35–42.03). Single neurological level T12 increased the chance of achieving WISCI II level 12 by 10 times (OR 10.2; 95% CI 3.8–27.36).
CONCLUSIONS: Orthotic walking for persons with motor complete low thoracic spinal cord injury is an achievable goal through a comprehensive rehabilitation program. The factors identified in this study will help rehabilitation professionals strategically select the ideal candidate for orthotic gait training.

Spinal Cord (2023) 61:224–230; https://doi.org/10.1038/s41393-023-00875-5

INTRODUCTION

Regaining the ability to walk is one of the top priorities of people suffering from spinal cord injury (SCI), irrespective of the severity and level of injury [1, 2]. Therefore, walking recovery has become the target of several rehabilitation approaches. Despite various methods like body weight supported training and neuromodulation techniques described in the literature to enhance walking recovery, there is no proven method to entirely reverse the paralysis caused by SCI [3]. Persons with incomplete SCI at any neurological level with American spinal injury association Impairment Scale (AIS) C or D may achieve walking with or without appliances [4]. Lower extremity strength, time since injury, age, and upper extremity strength are factors known to influence the walking potential in these patients [5, 6].

The chance of persons with motor complete injury (AIS A & B) achieving the goal of walking is limited [7]. They are trained to be maximally independent in a wheelchair. However, patients with low thoracic level (T9–T12) and lumbar-level SCI may achieve walking with orthotic devices and walking aids [8]. Low thoracic SCI (LT-SCI) patients would require bilateral knee ankle-foot orthoses (KAFOs) and patients with lumbar-level spinal cord injury require ankle-foot orthoses to stand and walk [2].

Ambulatory training with KAFOs for LT-SCI is intensive and challenging. It requires huge determination and motivation from the patients. A level of 12 on the Walking Index for Spinal Cord Injury (WISCI) is the maximum possible score that can be achieved using these orthotic devices. They can usually walk short distances, with slow average velocities and greatly increased energy expenditure [9–12]. Despite these challenges, walking is beneficial for them due to the many physiological and psychological benefits such as the lowered risk of complications such as osteoporosis, improved body image [13–15], better functioning of the gastrointestinal, urologic, cardiovascular, and respiratory systems [16, 17].

Moreover, most of the barriers to community reintegration are related to the environmental accessibility of homes and public buildings as well as transportation [18–20]. Removing these barriers to make people mobile in a wheelchair is a difficult task in low and middle-income countries (LMICs) due to limited resources. Hence, exploring the maximum walking potential of patients through restorative or compensatory gait training programs has become a mandated goal of rehabilitation in LMICs.

Our rehabilitation center is one of the few centers that enable persons with motor complete LT-SCI to walk independently using polypropylene KAFOs and elbow crutches. Though such a gait

[1] Department of Physical Medicine and Rehabilitation, Christian Medical College, Vellore, India. [2] Department of Biostatistics, Christian Medical College, Vellore, India.
✉email: senthil@cmcvellore.ac.in

Received: 1 April 2022 Revised: 4 January 2023 Accepted: 9 January 2023
Published online: 25 January 2023

training protocol has been followed successfully for the last 50 years, there is hardly any published data available from our center. In this retrospective study, we have aimed to present the data on the orthotic walking-related outcomes of patients with LT-SCI who have been rehabilitated in our center. We believe that the results of this study will help rehabilitation professionals to identify appropriate patients for orthotic gait training.

METHODS

Setting

The Rehabilitation Institute at Christian Medical College, Vellore, India, is a 100-bedded inpatient rehabilitation unit that provides multidisciplinary rehabilitation, primarily for persons with SCI. Patients are admitted to this center once they are medically stable and ready for an intensive, multidisciplinary rehabilitation program. The entire rehabilitation process is self-funded and the rehabilitation team members decide the length of stay through the goal negotiation process.

The motor complete LT-SCI patients admitted at our center are trained to be wheelchair independent and are also considered for orthotic walking training. If the patient has the potential and interest, he/she is exposed to the orthotic gait training program. The duration of training is two hours per day and six days per week for 12 weeks. This 12-week progressive orthotic gait training program is split into 3 phases. In phase I (0–6 weeks), the gait training is initiated in the parallel bars progressing to walking with a walker. Patients are trained to walk with reciprocal gait patterns using pelvic hitching. The latissimus dorsi muscle is trained explicitly for this purpose [21]. At the end of 6 weeks, the patient is expected to achieve independent walking using a reciprocal walker. An assessment is made at this point to evaluate the possibility of progression to gait training with elbow crutches. Those patients with a lack of trunk control will be discharged home having attained the goal of limited household walking with a walker. In the second phase of gait training (6–10 weeks), all the eligible patients are progressively trained with bilateral elbow crutches. At the end of this phase, the patient is expected to walk independently using elbow crutches with a reciprocal gait pattern. In phase III (11–12 weeks), the patient is trained to perform advanced walking skills such as stair climbing, rough terrain, and curbs negotiation along with simulated community walking to improve confidence level. During the entire 12 weeks, patients undergo progressive upper extremity strength training to build the key muscles. The detailed week-wise training program along with a training video is available as a Supplementary file.

Participants

The medical records of persons with motor complete LT-SCI (AIS A and B) admitted between January 2005 and June 2015 for a comprehensive rehabilitation program in our institution were retrospectively reviewed.

The inclusion criteria were as follows: (1) traumatic and nontraumatic LT-SCI (T9–T12); (2) motor complete (AIS A & B) injury; (3) male and female patients of all ages (4), patients who underwent inpatient rehabilitation program between January 1, 2005, and June 30, 2015; (5) completed a minimum of 6 weeks inpatient rehabilitation program.

The exclusion criteria were as follows: (1) Single NLI above T9 (2) Patients with motor incomplete injury (AIS C and D); (3) Premorbid neurological or musculoskeletal comorbidities which compromised patients' walking before the injury (4) Admission for a purpose other than gait training; (5) Early discharge (within six weeks of admission) due to family or social reasons; (6) Medical reports without sufficient information on walking outcomes.

We extracted relevant information from patients' medical reports and recorded them in a data-collection form, and subsequently entered them into a database. All information in the database was verified for accuracy by an independent researcher with the data-collection form. Any discrepancies noted were corrected. The data were de-identified to maintain patient privacy.

We collected data that included: (1) Demographic variables- gender, age, and employment status; (2) Injury-related variables- cause of injury, mode of injury, time since injury, level of injury, AIS grade, associated injuries, surgical stabilization, muscle tone, the strength of abdominal muscles (presence of Beevor's sign) [22]; (3) Treatment, and other relevant information during the rehabilitation period - complications, length of stay (LOS) and ambulatory status at the time of discharge (WISCI II level), walking speed and endurance. The walking speed was a record of the distance covered in a minute and the walking endurance was a record of the distance covered by walking continuously without a break.

The Ethics Committee of Christian Medical College approved the study and waived the requirement to obtain patients' written informed consent (IRB min. No 9665 dated 23/09/2015).

Analysis

Data were presented as mean (SD) for continuous variables and frequency along with percentage for categorical variables. Univariate associations of clinical and demographic predictors with the walking outcome were analyzed using chi-square statistics and the effect size was presented as an odds ratio (95% CI). Multivariate logistic regression was performed with a stepwise approach with removal criteria of p-value < 0.20 to determine the factors predicting walking outcomes. Data analysis was done using STATA 16.1/IC.

RESULTS

General characteristics

A total of 789 medical reports of patients with LT-SCI were identified during the study period. From the identified reports, 356 reports were excluded due to the following reasons: 138 patients had AIS C and D, 198 patients were admitted for reasons other than walking training such as bladder & bowel retraining, pressure ulcer management, 22 patients were discharged early due to family and social causes, and two patients had lack of information on walking outcome. Among the 431 data identified, one patient with transgender was excluded to minimize the data variability. Finally, the data from 430 patients were considered appropriate and analyzed. A summary of the demographic characteristics and clinical presentations of all the patients is presented in Table 1.

Among the 430 patients, 89.1% ($n = 383$) were males, and the average age of the participants was 32.3 (±11.1) years. Most of the participants were in the age group between 16 and 30 years ($n = 204$, 47.4%). While trauma was the leading cause of SCI ($n = 384$, 89.3%), falls ($n = 254$, 59.1%) were the primary mode of injury. The mean time from the injury to the onset of rehabilitation was 15.4 (±34) months.

Single NLI T12 ($n = 174$, 40.2%) was more frequent among the LT-SCI followed by single NLI T10 ($n = 125$, 28.9%). Forty-five patients (10.6%) had associated injuries in their upper or lower extremities. A majority of patients had spinal stabilization surgery before admission to the rehabilitation institute ($n = 339$, 78.8%). Two hundred and sixteen patients (50.2%) had positive Beevor's sign indicating weak lower abdominal muscles. Only 67 patients (15.7%) had spasticity. Ninety-one percent of people ($n = 395$) had AIS A. Pressure ulcers were noted as the major complication in the study population ($n = 148$, 34.2%). The mean length of stay for rehabilitation was 10.3 (±4) weeks.

Walking outcome

Among the 430 patients, 260 (60.5%) patients achieved WISCI II level 12 (Walking with long braces and elbow crutches), and 105 (24.2%) achieved WISCI II level 9 (Walking with long braces and walker) at the time of discharge. The highest proportion of those who achieved walking among the LT-SCI was single NLI-T12 (43%). People with WISCI level 12 ($n = 234$; missing data = 26) were able to walk with a mean speed of 17.8 (±5.8) meters/min and covered a mean distance of 376 (±179.7) meters. People with WISCI level 9 ($n = 80$; missing data = 25) were able to walk with a mean speed of 8.2 (±5.8) meters/min and covered a mean distance of 215.5 (±104.6) meters at the time of discharge.

Table 2 shows the univariate and multivariate logistic regression analysis of the predictors of orthotic walking outcomes (WISCI II level 9 and 12). Out of 11 clinical parameters considered, eight of them were found to be significant predictors of walking in the univariate analysis. Age, gender, time since the injury of less than 6 months, cause of injury, single neurological level, spasticity, and

Table 1. The characteristics of patients recruited for the study (variables presented as %).

Variables	T9 ($n = 41$)	T10 ($n = 125$)	T11 ($n = 90$)	T12 ($n = 174$)	Total ($n = 430$)
Gender					
Male	36 (8.4)	113 (26.3)	77 (17.9)	157 (36.5)	383 (89.1)
Female	5 (1.2)	12 (2.7)	13 (3)	17 (4)	47 (10.9)
Age group, years					
≤15	0 (0)	2 (0.5)	2 (0.5)	7 (1.6)	11 (2.6)
16–30	22 (5.1)	60 (13.9)	42 (9.8)	80 (18.6)	204 (47.4)
31–45	11 (2.6)	43 (10)	37 (8.6)	66 (15.3)	157 (36.5)
46–60	7 (1.6)	19 (4.4)	9 (2.1)	18 (4.2)	53 (12.3)
61–75	1 (0.2)	1 (0.2)	0 (0)	3 (0.7)	5 (1.2)
Time since injury					
≤6 months	24 (5.6)	70 (16.3)	44 (10.2)	87 (20.2)	225 (52.3)
>6 months	17 (3.9)	55 (12.8)	46 (10.7)	87 (20.2)	205 (47.7)
Vocation					
Salaried employment	8 (1.9)	24 (5.6)	13 (3)	28 (6.5)	73 (17)
Self-employed	4 (0.9)	8 (1.9)	6 (1.4)	7 (1.6)	25 (5.8)
Daily waged	6 (1.4)	12 (2.8)	10 (2.3)	20 (4.6)	48 (11.1)
Farmer	1 (0.2)	5 (1.2)	5 (1.2)	15 (3.5)	26 (6.1)
Student	10 (2.3)	20 (4.6)	8 (1.9)	20 (4.6)	58 (13.5)
Unemployed/homemaker	1 (0.2)	5 (1.2)	4 (0.9)	8 (1.9)	18 (4.2)
Missing information	11 (2.5)	51 (11.9)	44 (10.2)	76 (17.7)	182 (42.3)
Etiology					
Traumatic	34 (7.9)	110 (25.6)	82 (19.1)	158 (36.7)	384 (89.3)
Nontraumatic	7 (1.6)	15 (3.5)	8 (1.9)	16 (3.7)	46 (10.7)
Mode of injury					
RTA	11 (2.5)	31 (7.2)	18 (4.2)	52 (12.1)	112 (26)
Fall	21 (4.9)	75 (17.4)	58 (13.5)	100 (23.3)	254 (59.1)
Infection	3 (0.7)	6 (1.4)	4 (0.9)	4 (0.9)	17 (3.9)
Transverse myelitis	1 (0.2)	2 (0.5)	1 (0.2)	2 (0.5)	6 (1.4)
Tumor	1 (0.2)	5 (1.2)	0 (0)	2 (0.5)	8 (1.9)
Others[a]	4 (0.9)	6 (1.4)	9 (2.1)	14 (3.3)	33 (7.7)
AIS level					
A	39 (9.1)	118 (27.4)	86 (20)	152 (35.3)	395 (91.9)
B	2 (0.5)	7 (1.6)	4 (0.9)	22 (5.1)	35 (8.1)
Surgical stabilization					
Yes	34 (7.9)	95 (22.1)	73 (17)	137 (31.9)	339 (78.8)
No	1 (0.5)	14 (3.1)	8 (1.9)	20 (4.6)	43 (10.1)
Not applicable	6 (1.4)	7 (1.6)	6 (1.4)	11 (2.5)	30 (6.9)
Missing information	0 (0)	9 (2.1)	3 (0.7)	6 (1.4)	18 (4.2)
Spasticity					
No	32 (7.6)	107 (24.7)	80 (18.7)	144 (33.3)	363 (84.3)
Yes	9 (2.1)	18 (4.2)	10 (2.3)	30 (7.1)	67 (15.7)
Beevor's sign					
Positive	38 (8.8)	100 (23.3)	55 (12.8)	23 (5.3)	216 (50.2)
Negative	3 (0.7)	25 (5.8)	35 (8.1)	151 (35)	214 (49.8)
Associated injuries					
Yes	4 (0.9)	20 (4.6)	5 (1.4)	16 (3.7)	45 (10.6)
No	37 (8.8)	105 (24.2)	85 (19.9)	158 (36.5)	385 (89.4)
Complication					
Pressure ulcers	15 (3.5)	35 (8.1)	36 (8.4)	62 (14.4)	148 (34.4)
Heterotrophic ossification	1 (0.2)	7 (1.6)	1 (0.2)	3 (0.7)	12 (2.8)

Table 1. continued

Variables	T9 (*n* = 41)	T10 (*n* = 125)	T11 (*n* = 90)	T12 (*n* = 174)	Total (*n* = 430)
Deep vein thrombosis	1 (0.2)	7 (1.6)	1 (0.2)	4 (0.9)	13 (3)
Nil	24 (5.6)	76 (17.7)	52 (12.1)	105 (24.4)	257 (59.8)
Length of stay					
≤12 weeks	26 (6)	77 (17.9)	59 (13.7)	110 (25.6)	272 (63.2)
>12 weeks	15 (3.5)	48 (11.2)	31 (7.2)	64 (14.9)	158 (36.8)
WISCI II Level					
Level 0	16 (3.7)	17 (3.9)	15 (3.5)	17 (3.9)	65 (15.1)
Level 9	14 (3.2)	41 (9.5)	21 (4.9)	29 (6.7)	105 (24.4)
Level 12	11 (2.5)	67 (15.6)	54 (12.6)	128 (29.8)	260 (60.5)

[a]Others include, assault, sports injury, gunshot injury.

length of stay were found to be significantly predicting the walking outcome. Multivariate logistic regression revealed that people with the age less than 30 years have an increased chance of achieving either WISCI II level 9 or 12 by 17 times than those older. Similarly, male gender (OR 5.66; 95% CI, 2.38–13.44), TSI less than 6 months (OR 2.39; 95% CI 1.15–5.01), single NLI T10 (OR 6.48; 95% CI, 2.34–17.94), NLI T11 (OR 3.36; 95% CI, 1.2–9.4), NLI-T12 (OR 4.18; 95% CI, 1.36–12.86), negative Beevor's sign (OR 2.45; 95% CI, 1.05–5.71), and length of stay more than 12 weeks (OR 2.4; 95% CI, 1.15–5.01) also increased the chance of achieving orthotic walking after LT-SCI.

Table 3 shows the univariate and multivariate logistic regression analysis of factors predicting achievement of WISCI II level 12. Multivariate analysis revealed only three parameters predicting the achievement of WISCI II level 12. Age, single NLI T10 & below, and etiology of the SCI were the factors that predicted the achievement of WISCI II level 12. Age less than 30 years (OR 9.96; 95% CI 4.08–24.3) and the single NLI T12 (OR 10.2; 95% CI 3.8–27.36) increased the chance of achieving WISCI II level 12 by 10 times. Though negative Beevor's sign (strong abdominal muscles) showed significant prediction in univariate analysis (OR 2.1; 95% CI 1.33–3.35), it did not demonstrate in multivariate analysis.

DISCUSSION

The primary aim of this study was to depict the orthotic walking outcome of persons with motor complete LT-SCI (AIS A and B) who were admitted to a comprehensive rehabilitation program. To our knowledge, this retrospective study is the first of its kind in exploring the orthotic walking outcomes of this cohort. Our results show that 84.9% (n = 365) of people achieved walking using orthoses and walking aid either with a walker (WISCI II level 9, *n* = 105) or elbow crutches (WISCI II level 12, *n* = 260).

Waters et al. [23] and Ditunno et al. [2] reported that the predicted functional walking is 0% and 8.5%, respectively after one-year post-injury, for persons with AIS A thoracic level of lesion. These study results indicate that the functional recovery chances are limited with complete injury. Compensatory rehabilitation strategies are used when neurological recovery is not possible.

The rehabilitation program for patients with SCI focuses on achieving independence in functional activities such as self-care and vocation. The wheelchair-accessible public places and wheelchair-friendly architecture in developed nations circumvent the need for undertaking the highly demanding orthotic walking program. Hence, such vigorous orthotic gait training often is not emphasized in developed nations for persons with LT-SCI. However, in LMICs, where wheelchair accessibility in the community is a significant hurdle, walking with orthoses gives individuals a better chance of community reintegration [24, 25]. A study by Samuelkamaleshkumar et al. (2010) identified that persons with SCI in rural South India who have completed comprehensive rehabilitation with an emphasis on achieving functional ambulation show a high level of community reintegration in physical independence, social integration, and cognitive independence [26].

Unlike the other orthotic devices (LS-KAFO, walkabout orthoses, reciprocating gait orthosis) described for persons with LT-SCI, the polypropylene solid AFO with aluminum uprights is a relatively lightweight orthosis. Bilateral KAFOs weigh approximately 3 kgs (6.5 lbs). Though ambulation with knees locked in full extension increases the energy cost, it provides safety. Locked knees allow the patient to lean backward, placing the center of mass of the trunk behind the hip joint resulting in tightening of the anterior hip capsule, thus providing internal stabilization of the hip [27]. The positive drop lock enables the individuals to lock and unlock the knees as needed during standing, walking, and sitting on a chair. Polypropylene KAFO can be worn underneath clothes and is cosmetically more acceptable than other devices.

Few people use orthotic walking as the primary mode of walking. Many others would decline due to the various associated challenges such as the functional use of hands, fear of falls, difficulty negotiating steps & uneven terrain, difficulty donning and doffing orthosis, the appearance, and bulkiness of the orthoses, as well as the need for substantial energy expenditure, as high as 3–9 times that of the normal population, which leads to early fatigue [10, 28, 29]. Because the legs are paralyzed, the primary contributors to walking are the upper extremity and trunk muscles. Selective strengthening of the trunk and upper extremity muscles improves gait performance and postpones fatigue and shoulder pain [30].

Under these circumstances, patients who wish to ambulate with KAFOs should be given precise information regarding the advantages and disadvantages of orthotic ambulation rather than an adulated impression.

Though orthotic walking has slow velocity and high energy expenditure, it is still considered. Literature suggests a walking speed of 0.59 m/s (35.4 m/min) is essential for independent community walking following SCI [31]. Our study result showed an average speed of 17.8 m/min, for people who walked with elbow crutches. This is only half of the expected walking speed for successful community walking. Therefore these patients can only be limited community walkers. However, these values were taken at the time of discharge, and walking velocity can continue to improve over time. Data on the walking speed of persons with LT-SCI walking with KAFOs and elbow crutches are not available in the literature.

Since this method of walking requires high energy and the risk of falls is high, the selection of the ideal candidate is crucial.

Table 2. Univariate and multivariate logistic regression analysis showing the predictors of orthotic walking ability (WISCI II level 9 and level 12) after LT-SCI.

Variables	WISCI II level 0	WISCI II levels 9 and 12	Univariate		Multivariate	
	(*n* = 65)	(*n* = 365)	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Gender						
Male	51 (78.5)	332 (91)	2.76 (1.38–5.51)	0.004	5.66 (2.38–13.44)	<0.0001
Female	14 (21.5)	33 (9)	Ref.			
Age group, years						
≤30	17 (26.2)	198 (54.3)	10.87 (5.32–22.2)	<0.0001	17.58 (7.35–42.03)	<0.0001
31–45	20 (30.8)	137 (37.5)	6.44 (3.21–12.9)	<0.0001	7.24 (3.22–16.29)	<0.0001
>45	28 (43)	30 (8.2)	Ref.			
Time since injury						
<6m	27 (41.5)	198 (54.3)	1.67 (0.98–2.85)	0.04	2.39 (1.15–5.01)	0.01
>6m	38 (58.5)	167 (45.7)	Ref.			
Etiology						
Traumatic	50 (76.9)	334 (91.5)	3.23 (1.63–6.41)	0.001	1.96 (0.84–4.61)	0.12
Nontraumatic	15 (23.1)	31 (8.5)	Ref.			
AIS level						
A	58 (89.2)	337 (92.3)	Ref.			
B	7 (10.8)	28 (7.7)	0.69 (0.29–1.65)	0.4	–	–
Neurological level of injury						
T9	16 (24.5)	25 (6.8)	Ref.			
T10	17 (26.2)	108 (29.6)	4.07 (1.81–9.34)	0.001	6.48 (2.34–17.94)	<0.0001
T11	15 (23.1)	75 (20.6)	3.24 (1.4–7.49)	0.006	3.36 (1.2–9.4)	0.02
T12	17 (26.2)	157 (43)	5.9 (2.65–13.19)	<0.0001	4.18 (1.36–12.86)	0.01
Spasticity						
No	49 (75.4)	313 (85.8)	1.97 (1.04–3.71)	0.04	–	–
Yes	16 (24.6)	52 (14.2)	Ref.			
Beevor's sign						
Negative	20 (30.8)	194 (53)	2.55 (1.5–4.49)	0.001	2.45 (1.05–5.71)	0.04
Positive	45 (69.2)	171 (47)	Ref.			
Complication						
No	44 (66.7)	215 (58.9)	0.68 (0.39–1.2)	0.18	–	–
Yes	21 (33.3)	150 (41.1)	Ref.			
Associated injuries						
No	55 (84.6)	330 (90.4)	1.72 (0.81–3.66)	0.16	2.54 (0.95–9.76)	0.06
Yes	10 (15.4)	35 (9.6)	Ref.			
Length of stay						
≤12 weeks	52 (80)	220 (60.3)	Ref.			
>12 weeks	13 (20)	145 (39.7)	2.64 (1.39–5.01)	0.003	2.4 (1.15–5.01)	0.02

Values are presented as *n* (%), and *p*-value less than 0.05 is considered as significant.

According to the study results, younger adults (<30 years) with traumatic SCI and a single neurological level of T10 & below can perform better than others with orthotic gait training after LT-SCI.

Moreover, this limited community walking needs to be combined with a wheelchair or tricycle for better community participation. Most of our rehabilitated individuals with LT-SCI use a combination of orthotic walking and hand-pedaled tricycles for better community participation.

Limitations and future research

Our study has several limitations- (1) Data on walking speed, initial management, and anthropometric details were partly missing (2). WISCI II was the only walking outcome-related score available. Details of other functional independence measures were not available (3). Since the data was extracted from a lengthy time frame, multiple therapists would have been involved in the evaluation and intervention. However, this is a common problem in any retrospective study done for a lengthy period (4). The information regarding the zone of partial preservation of sensation and motor functions was not documented in the medical reports.

The learning from this retrospective study is that persons with LT-SCI have a high chance of achieving orthotic walking. Choosing the right candidate for such intensive rehabilitation is vital. Functional walking with KAFO and elbow crutches can be considered only for candidates with less than 30 years of age and a single neurological level of T10 and below. Determination of the individual to undergo such intensive gait training protocol and

Table 3. Univariate and multivariate logistic regression analysis showing the predictors of achieving WISCI II level 12 after LT-SCI.

Variables (%)	WISCI II level 9	WISCI II level 12	Univariate		Multivariate	
	(n = 105)	(n = 260)	OR (95% CI)	p-value	OR (95% CI)	p-value
Gender						
Male	95 (90.5)	237 (91.2)	1.08 (0.5–2.36)	0.84	–	–
Female	10 (9.5)	23 (8.8)	Ref.			
Age group, years						
≤30	33 (31.4)	165 (63.5)	7.5 (3.3–17.03)	0.0001	9.96 (4.08–24.3)	<0.0001
31–45	54 (51.4)	83 (31.9)	2.34 (1.03–5.17)	0.04	2.31 (0.98–5.45)	0.06
>45	18 (17.2)	12 (4.6)	Ref.			
Time since injury						
<6m	60 (57.1)	138 (53.1)	0.85 (0.53–1.34)	0.48	–	–
>6m	45 (42.9)	122 (46.9)	Ref.			
Etiology						
Traumatic	90 (85.7)	244 (94)	2.54 (1.21–5.35)	0.01	2.96 (1.26–6.97)	0.01
Nontraumatic	15 (14.3)	16 (6)	Ref.			
AIS level						
A	94 (89.5)	243 (93.5)	Ref.			
B	11 (10.5)	17 (6.5)	0.6 (0.27–1.32)	0.21	–	–
Neurological level of injury						
T9	14 (13.4)	11 (4.2)	Ref.			
T10	41 (39)	67 (25.7)	2.08 (0.86–5.01)	0.1	3.37 (1.28–8.86)	0.01
T11	21 (20)	54 (21.1)	3.27 (0.128–8.35)	0.01	5.58 (1.98–15.75)	0.001
T12	29 (27.6)	128 (49)	5.62 (2.31–13.63)	<0.0001	10.2 (3.8–27.36)	<0.0001
Spasticity						
No	88 (83.8)	225 (86.5)	1.24 (0.66–2.33)	0.5	–	–
Yes	17 (16.2)	35 (13.5)				
Beevor's sign						
Negative	42 (40)	152 (58.5)	2.1 (1.33–3.35)	0.002	–	–
Positive	63 (60)	108 (41.5)	Ref.			
Complication						
No	62 (59)	153 (58.8)	0.99 (0.63–1.57)	0.97	–	–
Yes	43 (41)	107 (41.2)	Ref.			
Associated injuries						
No	97 (92.4)	233 (89.6)	0.71 (0.31–1.62)	0.42	–	–
Yes	8 (7.6)	27 (10.4)	Ref.			
Length of stay						
≤12 weeks	64 (61)	156 (60)	Ref.			
>12 weeks	41 (39)	104 (40)	1.04 (0.65–1.66)	0.87	–	–

Values are presented as n (%), and p-value less than 0.05 is considered as significant.

a dedicated rehabilitation team is also important. The non-availability of the data in the medical records reinforces the need for better documentation and the use of quantitative clinical outcome measures. The information collected through databases will facilitate informed decision-making in the rehabilitation process. Follow-up studies should evaluate the sustainability of orthotic walking and how it had benefited the patient in enhanced community reintegration.

CONCLUSIONS

Orthotic walking for persons with motor complete low thoracic spinal cord injury (AIS A and B) is an achievable goal through a structured comprehensive rehabilitation program. The majority of the patients achieved orthotic walking with a walker or crutches. Factors like age, neurological level, and cause of injury significantly predicted the walking outcome. The sustainability of such orthotic walking needs to be addressed in future studies.

DATA AVAILABILITY

The datasets generated for the current study are not publicly available in order to maintain patient confidentiality but are available on reasonable request.

REFERENCES

1. Simpson LA, Eng JJ, Hsieh JTC. Wolfe and the Spinal Cord Injury Rehabilitation Evidence (SCIRE) Research Team DL. The health and life priorities of individuals with spinal cord injury: a systematic review. J Neurotrauma. 2012;29:1548–55.

2. Ditunno PL, Patrick M, Stineman M, Ditunno JF. Who wants to walk? Preferences for recovery after SCI: a longitudinal and cross-sectional study. Spinal Cord. 2008;46:500–6.
3. Donovan J, Snider B, Miller A, Kirshblum S. Walking after spinal cord injury: current clinical approaches and future directions. Curr Phys Med Rehabil Rep. 2020;8:149–58.
4. van Middendorp JJ, Hosman AJF, Pouw MH, EM-SCI Study Group, Van de Meent H. ASIA impairment scale conversion in traumatic SCI: is it related with the ability to walk? A descriptive comparison with functional ambulation outcome measures in 273 patients. Spinal Cord. 2009;47:555–60.
5. Crozier KS, Cheng LL, Graziani V, Zorn G, Herbison G, Ditunno JF, et al. Spinal cord injury: prognosis for ambulation based on quadriceps recovery. Paraplegia. 1992;30:762–7.
6. Waters RL, Adkins RH, Yakura JS, Sie I. Motor and sensory recovery following incomplete paraplegia. Arch Phys Med Rehabil. 1994;75:67–72.
7. Burns AS, Marino RJ, Flanders AE, Flett H. Clinical diagnosis and prognosis following spinal cord injury. Handb Clin Neurol. 2012;109:47–62.
8. Ditunno JF, Scivoletto G, Patrick M, Biering-Sorensen F, Abel R, Marino R, et al. Validation of the walking index for spinal cord injury in a US and European clinical population. Spinal Cord. 2008;46:181–8.
9. Vaccaro AR, Daugherty RJ, Sheehan TP, Dante SJ, Cotler JM, Balderston RA, et al. Neurologic outcome of early versus late surgery for cervical spinal cord injury. Spine. 1997;22:2609–13.
10. Bernardi M, Canale I, Castellano V, Di Filippo L, Felici F, Marchetti M, et al. The efficiency of walking of paraplegic patients using a reciprocating gait orthosis. Paraplegia. 1995;33:409–15.
11. Bowker P, Messenger N, Ogilvie C, Rowley DI. Energetics of paraplegic walking. J Biomed Eng. 1992;14:344–50.
12. Hirokawa S, Grimm M, Le T, Solomonow M, Baratta RV, Shoji H, et al. Energy consumption in paraplegic ambulation using the reciprocating gait orthosis and electric stimulation of the thigh muscles. Arch Phys Med Rehabil. 1990;71:687–94.
13. Ogilvie C, Bowker P, Rowley DI. The physiological benefits of paraplegic orthotically aided walking. Paraplegia 1993;31:111–5.
14. Le Fort M, Espagnacq M, Perrouin-Verbe B, Ravaud J-F. Risk analyses of pressure ulcer in tetraplegic spinal cord-injured persons: a French long-term survey. Arch Phys Med Rehabil. 2017;98:1782–91.
15. Fuentes CT, Pazzaglia M, Longo MR, Scivoletto G, Haggard P. Body image distortions following spinal cord injury. J Neurol Neurosurg Psychiatr. 2013;84:201–7.
16. Karimi MT. Evidence-based evaluation of physiological effects of standing and walking in individuals with spinal cord injury. Iran J Med Sci. 2011;36:242–53.
17. Massucci M, Brunetti G, Piperno R, Betti L, Franceschini M. Walking with the advanced reciprocating gait orthosis (ARGO) in thoracic paraplegic patients: energy expenditure and cardiorespiratory performance. Spinal Cord. 1998;36:223–7.
18. Barclay L, McDonald R, Lentin P, Bourke-Taylor H. Facilitators and barriers to social and community participation following spinal cord injury. Aust Occup Ther J. 2016;63:19–28.
19. Gupta S, Jaiswal A, Norman K, DePaul V. Heterogeneity and its impact on rehabilitation outcomes and interventions for community reintegration in people with spinal cord injuries: an integrative review. Top Spinal Cord Inj Rehabil. 2019;25:164–85.
20. Kashif M, Jones S, Darain H, Iram H, Raqib A, Butt AA, et al. Factors influencing the community integration of patients following traumatic spinal cord injury: a systematic review. J Pak Med Assoc. 2019;69:1337–43.
21. Butler PB, Major RE, Patrick JH. The technique of reciprocal walking using the hip guidance orthosis (hgo) with crutches. Prosthet Orthot Int. 1984;8:33–8.
22. McCarter SJ, Burkholder DB, Klaas JP, Boes CJ. Charles E. Beevor's lasting contributions to neurology: More than just a sign. Neurology 2018;90:513–7.
23. Waters 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;75:756–60.
24. Senthilvelkumar T, Chandy BR. Paraplegia and transtibial amputation: successful ambulation after dual disability: a retrospective case report. Spinal Cord Ser Cases. 2017;3:16039.
25. Sekaran P, Vijayakumari F, Hariharan R, Zachariah K, Joseph SE, Kumar RKS, et al. Community reintegration of spinal cord-injured patients in rural south India. Spinal Cord. 2010;48:628–32.
26. Samuelkamaleshkumar S, Radhika S, Cherian B, Elango A, Winrose W, Suhany BT, et al. Community reintegration in rehabilitated South Indian persons with spinal cord injury. Arch Phys Med Rehabil. 2010;91:1117–21.
27. Nene AV, Hermens HJ, Zilvold G. Paraplegic locomotion: a review. Spinal Cord. 1996;34:507–24.
28. Cerny K, Perry J, Walker JM. Effect of an unrestricted knee-ankle-foot orthosis on the stance phase of gait in healthy persons. Orthopedics. 1990;13:1121–7.
29. Nakhaee K, Farahmand F, Salarieh H. Studying the effect of kinematical pattern on the mechanical performance of paraplegic gait with reciprocating orthosis. Proc Inst Mech Eng H. 2012;226:600–11.
30. Baniasad M, Farahmand F, Arazpour M, Zohoor H. Role and significance of trunk and upper extremity muscles in walker-assisted paraplegic gait: a case study. Top Spinal Cord Inj Rehabil. 2018;24:18–27.
31. van Silfhout L, Hosman AJF, Bartels RHMA, Edwards MJR, Abel R, Curt A, et al. Ten meters walking speed in spinal cord–injured patients: does speed predict who walks and who rolls? Neurorehabil Neural Repair. 2017;31:842–50.

ACKNOWLEDGEMENTS

We thank Ms. Anumeha Srivastava, Ms. Gokilam, Ms. Gowri, and Ms. Nivethanjali for their contribution to data extraction and compilation. No third-party funding was used.

AUTHOR CONTRIBUTIONS

TS was responsible for designing the study protocol, conducting the search, and writing the report. PC and BRC were responsible for screening potentially eligible studies and extracting data. SK and MV were responsible for the data entry, verification, and report writing. GR is responsible for analyzing data, interpreting results, and creating tables. RT and JG were responsible for reviewing and final approval of the material.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICAL APPROVAL

The Ethics Committee of Christian Medical College approved the study and waived the requirement to obtain patients' written informed consent (IRB min. No 9665 dated 23/09/2015).

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41393-023-00875-5.

Correspondence and requests for materials should be addressed to Thangavelu Senthilvelkumar.