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ARTICLE

Changes in bowel function following exoskeletal-assisted walking in persons with spinal cord injury: an observational pilot study

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Abstract

Study design Prospective, observational study.

Objective To explore the effects of exoskeletal-assisted walking (EAW) on bowel function in persons with spinal cord injury (SCI).

Setting Ambulatory research facility located in a tertiary care hospital.

Methods Individuals 18–65 years of age, with thoracic vertebrae one (T1) to T11 motor-complete paraplegia of at least 12 months duration were enrolled. Pre- and post-EAW training, participants were asked to report on various aspects of their bowel function as well as on their overall quality of life (QOL) as related to their bowel function.

Results Ten participants completed 25–63 sessions of EAW over a period of 12–14 weeks, one participant was lost to follow up due to early withdrawal after ten sessions. Due to the small sample size, each participant's results were presented descriptively in a case series format. At least 5/10 participants reported improvements with frequency of bowel evacuations, less time spent on bowel management per bowel day, fewer bowel accidents per month, reduced laxative and/or stool softener use, and improved overall satisfaction with their bowel program post-EAW training. Furthermore, 8/10 reported improved stool consistency and 7/10 reported improved bowel function related QOL. One participant reported worsening of bowel function post-EAW.

Conclusion Between 50 and 80% of the participants studied reported improvements in bowel function and/or management post-EAW training. EAW training appeared to mitigate SCI-related bowel dysfunction and the potential benefits of EAW on bowel function after SCI is worthy or further study.

Introduction

Neurogenic bowel dysfunction is a common sequela of spinal cord injury (SCI) and occurs in 68–80% of individuals with SCI [1, 2]. When individuals with SCI were asked to list in order of importance the adverse effects of SCI on quality of life (QOL), bowel dysfunction was ranked second only to loss of mobility [3]. Bowel dysfunction secondary to SCI can lead to constipation, discoordination of defecation, and incontinence [2]. The degree of dysfunction can be affected by intrinsic characteristics of the SCI itself (e.g., level/completeness) or external factors (e.g., comorbidities/medications) and can create significant personal or socioeconomic burdens [4].

A typical SCI bowel program takes 30–60 min with most individuals being able to perform it in <45 min, but it is not uncommon to require >1 h to complete the task despite attempts at bowel program optimization [5, 6]. Individuals

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with tetraplegia have been found to perform bowel programs less often and take longer to perform than those with paraplegia, possibly because they require more assistance [5]. Another reason for shorter bowel program times in persons with paraplegia might be that mobility among those with paraplegia is greater than that of those with tetraplegia. In the general (non-SCI) population, exercise, specifically walking, is well known to stimulate bowel motility [7–9]. Gastric emptying has been shown to increase with moderate intensity treadmill exercise, possibly due to increased gastric pressures from abdominal muscle contractions [10]. The amount of exercise itself can be a physiological factor determining the rate of gastric emptying [11]. In other words, beyond the direct effects of SCI on gastrointestinal motility, the inability to walk may place individuals with SCI at greater risk for bowel dysfunction.

Prior studies have suggested that standing alone does not significantly improve bowel function in persons with SCI [12]. Body-weight supported treadmill training (BWSTT) has been shown to decrease time required for defecation and improve bowel sensation [13, 14]. Robot-assisted overground ambulation, which more closely mirrors walking, may be even superior to standard BWSTT in reducing defecation time and enema requirements [15]. Powered exoskeletons are robotic, externally motorized orthoses placed over paralyzed limbs to help standing, walking, climbing stairs (in Europe and Canada), and activities of daily living; they are US Food and Drug Administration Class II medical devices in terms of safety and effectiveness along with powered wheelchairs [16]. To date, various benefits of exoskeletal-assisted walking (EAW) have been demonstrated for mobility, balance, and energy expenditure in those with SCI [17–19].

Three studies have reported on the clinical effectiveness of powered EAW for improving bowel function in participants with SCI without serious adverse events [20–22]. One case study described a young individual with motor-incomplete paraplegia who, upon 6 months of powered EAW, reported improved bowel function [23]. One study found that 80% of participants did not report changes in bowel function after EAW, but among the 20% who did, 89% reported positive changes including fewer instances of incontinence and constipation, as well as decreased time and assistance needed for bowel management [24]. Another recent study found improved bowel function based on the Spinal Cord Independence Measure in acute SCI and on the International SCI Bowel Function Basic Data Set in chronic SCI, but the changes did not reach significance [25]. The effects of EAW on neurogenic bowel dysfunction in persons with SCI have yet to be better defined. This study therefore sought to further investigate patient-reported bowel function and bowel related QOL before and after EAW in persons with motor-complete paraplegia.

Methods

Study design and team

A prospective, observational study design with two repeated measures (pre- and post- intervention) was performed using a single group convenience sample. The study protocol was approved by the James J. Peters VA Medical Center Institutional Review Board (IRB #SPU-09-011) and registered on ClinicalTrials.gov (Identifier NCT01454570) where a more detailed list of all outcomes evaluated after EAW training in persons with paraplegia can be found (e.g., changes in mobility, balance, bowel/bladder function, spasticity, quality of life, body composition, etc.). Some of the preliminary bowel related outcomes evaluated in this study have been presented in oral and poster format to the Academy of SCI Professionals in 2013 and the American Gastroenterological Association in 2014 [26, 27].

The study team consisted of physicians in physiatry, neurology, and internal medicine who oversaw the evaluation and interviewing of participants, as well as a biomedical engineer, exercise physiologist, and physical therapist who helped with the EAW training sessions. All co-authors had access to the study data and have reviewed and approved the final manuscript.

Setting

Eligible persons with motor-complete paraplegia from the New York metropolitan area were recruited and enrolled from May 2011—November 2013. The study was conducted at the VA Rehabilitation Research & Development National Center for the Medical Consequences of SCI, which is located in the James J. Peters VA Medical Center (Bronx, New York).

Participants

Participants were included if they were between 18 and 65 years old, had motor-complete paraplegia (by definition T1 level of injury and below) for >12 months, reported being between 160 and 190 cm tall, weighed <100 kg and were able to sign for consent. Participants were excluded if any of the following potential confounding factors or safety restrictions to EAW training were applicable: paralyzing neurological condition other than SCI; severe medical illness, disease, or condition; lower extremity fracture in the past 2 years; hip T-score <−3.5 or bone mineral density <0.60 g/cm^2 at the distal femur and/or proximal tibia; severe spasticity (Modified Ashworth Score of 4) [28]; lower extremity heterotopic ossification; trunk, pelvic, or lower extremity pressure injury; flexion contracture limited to 35° at the hip and/or 20° at the knee; history of psychopathology that may conflict with study objectives; case of untreated/uncontrolled hypertension (systolic blood pressure >140 mmHg, diastolic >90 mmHg); pregnancy, and/or lactation. All participants had complete upper motor neuron injuries with regards to bowel function (i.e., none had flaccid sphincter tone). None of the participants received any other form of walking intervention.

Study procedures and intervention: EAW sessions

The powered exoskeletal system (ReWalk™, ReWalk Robotics Inc., Marlborough, MA) uses an external frame that supports the paralyzed individual at the legs and partially at the trunk. It has a backpack worn by the individual that houses the batteries and main computer which coordinates walking via the motorized lower extremity joints. Lofstrand crutches are used for balance and stability while standing and walking with the device. Participants were asked to attend 3–4 EAW sessions weekly with a goal of completing at least 25 sessions in 12–14 weeks. Each session consisted of donning the device, checking vitals, performing sit to stand, then walking for 30–90 min in the device, with occasional rest periods as required. More details on the ReWalk™ device and EAW training sessions, as well as details on the safety profile of EAW have been described in prior publications from the larger study by Fineberg et al. [29], Yang et al. [18], and Asselin et al. [17, 30].

Study outcomes: SCI and bowel function assessments

Severity of SCI assessment

The International Standards for Neurological Classification of SCI Exam was used to classify participants on the American Spinal Injury Association (ASIA) Impairment Scale as complete (AIS A) or motor complete/sensory incomplete (AIS B) as well as to determine their neurological level of injury [31].

Bowel function assessments

Three bowel function assessments were performed before and after EAW training. First, participants were asked ten questions adopted from the Modified Lynch Gastrointestinal (GI) Survey for Patients with SCI (Supplementary Table 1) [32]. Stool consistency was surveyed using the Bristol Stool Scale (BSS). The BSS is a widely used research and clinical tool for rating stool consistency in the treatment of various bowel diseases and uses pictures of stool consistency categories as examples for selection by the individual [33]. The BSS scale ranges from 1 (very hard lumps) to 7 (watery consistency); ideal stool consistency is scored as mid-range (4–5). Both the Modified Lynch GI Survey and BSS have been validated for the evaluation of bowel function in SCI.

Lastly, participants were also administered the SCI-QOL Bowel Management Difficulties Short Form Instrument, a 9-item version of a larger 26-item question bank validated for assessing the bowel function and bowel-related QOL in persons with SCI; higher scores indicate higher levels of difficulty and poorer QOL [34].

Statistical analyses

Individual values are reported for participant demographic and SCI characteristics. Statistical analyses were initially performed using Statview version 5.0 (Abacus, Inc.). However, our study failed to meet target sample size for adequate power, therefore it was determined that all findings would be most accurately presented as a descriptive case series with descriptive variables only. For the 9-item SCI-QOL Bowel Management Difficulties Short Form, a ≥10% change from baseline was determined as being a clinically significant difference in score based on prior literature from Sloan et al. [35].

Results

Nineteen participants provided informed consent to be screened for eligibility. Eleven were deemed eligible for the study. Ten of the eleven eligible participants completed 25–63 sessions of EAW over a period of 12–14 weeks whereas one participant (ID #6) was lost to follow up due to early withdrawal after ten sessions (Fig. 1). Each participant's changes to bowel function are presented descriptively as a case series. All participants had motor-complete paraplegia (AIS A or B) and levels of injury ranged from T1–T11. Further characteristics including age and duration of injury are listed for each individual participant (Table 1).

Among the ten participants who completed at least 25 sessions of EAW training, many reported improvements in various items from the questions adopted from the Modified Lynch GI Survey. For example, 5/10 reported improved frequency of bowel evacuations over the past week, 5/10 reported reduced time in minutes spent on having a bowel movement per bowel day, 6/10 reported fewer bowel accidents over the past month, and 7/10 reported decreased frequency of laxative and/or stool softener use over the past week post-EAW training. Furthermore, 6/10 participants reported improved overall satisfaction with their bowel programs over the past month and, in 8/10 participants, ratings of stool consistency

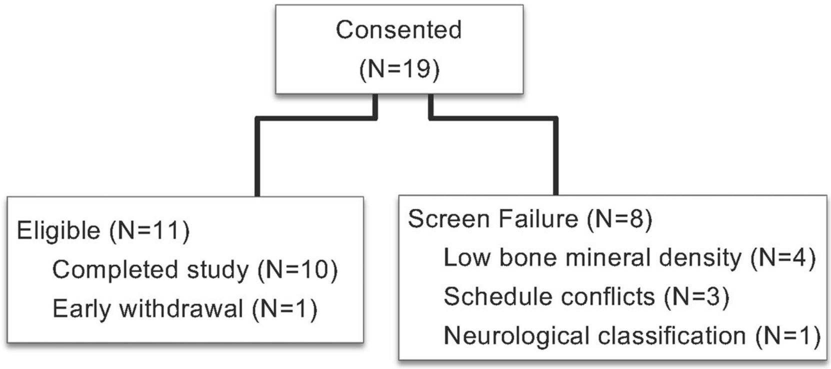

Fig. 1 Study consort diagram

Table 1 Characteristics of study participants

ID	Age range, years	Height, cm	Weight, kg	BMI, kg/m^2	Sex	Ethnicity	DOI range, years	LOI	AIS
1	31–45	173	67	22.3	M	Cauc.	6–10	T4	B
2	46–60	168	68	24.2	M	Cauc.	1–5	T10	A
3	31–45	183	79	23.7	M	Asian	1–5	T4	A
4	46–60	160	65	25.5	F	Cauc.	1–5	T8	A
5	61–65	175	73	23.6	M	Cauc.	11–15	T11	A
6[a]	18–30	185	75	21.8	M	Cauc.	1–5	T5	A
7	31–45	183	86	25.8	M	Cauc.	1–5	T1	B
8	46–60	175	84	27.3	M	Hisp.	1–5	T9	A
9	46–60	183	99	29.8	M	Cauc.	11–15	T7	A
10	31–45	170	64	21.9	M	A.A.	6–10	T2	A
11	61–65	173	73	24.4	M	Cauc.	1–5	T2	A

ID participant identification number, *BMI* body mass index, *M* Male, *F* Female, *Cauc.* Caucasian, *Hisp.* Hispanic, *A.A.* African American, *DOI* duration of injury

LOI level of injury (Thoracic Vertebral Level T1-T11); *AIS* American Spinal Injury Association Impairment Scale; *A* Motor and Sensory Complete Injury, *B* Motor Complete/Sensory Incomplete Injury

[a]Participant #6 was lost to follow up due to early withdrawal from the study

changed from either too hard or too watery to "ideal" (4–5) post-EAW training (Table 2).

Seven participants reported a ≥10% improvement on the SCI-QOL Bowel Management Difficulties Short Form Instrument while one participant reported a worsening of score (Table 3, Fig. 2). Of note, this participant (ID #11) also reported increased bowel accidents and medication use post-EAW training without changes in frequency of bowel evacuations, time spent on bowel management per bowel day, or overall satisfaction with regards to bowel program post-EAW training. Simultaneously, he reported a slight softening in stool consistency (6 to 5 on the BSS) (Table 2).

Discussion

In this sample of ten participants, 50–80% of the participants reported at least one or more improved aspects of their bowel function after EAW. As such, EAW appeared to mitigate several adverse aspects of neurogenic bowel dysfunction associated with SCI. At least half of the participants reported improvements with regard to frequency of bowel evacuations, time spent on bowel management per bowel day, number of bowel accidents, medication use, and overall satisfaction with their bowel programs post-EAW training. The majority of participants also reported improved stool consistency based on the Bristol Stool Scale and improved bowel function related QOL based on the SCI-QOL Bowel Management Difficulties Short Form Instrument. Of note though, one of the participants reported a worsening of bowel function post-EAW, including increased number of bowel accidents and medication use which were consistent with a poorer SCI-QOL score. The increased number of accidents may have been related to increased medication use and/or increased activity from EAW, but the exact relationship between these observations remains unclear. No other adverse events were reported by participants, consistent with the three studies to date that reported on the clinical effectiveness of EAW for improving bowel function in participants with SCI without serious adverse events [20–22].

Table 2 Participant-reported changes in bowel function following exoskeletal-assisted walking (EAW)

ID	# EAW sessions completed	Frequency of bowel evacuations (# per week)		Time spent per bowel day (# min)		Number of bowel accidents (# per month)		Laxative and/or stool softener use (frequency over the past week)		Overall satisfaction with bowel program (during the past month)		Bristol Stool Scale (1 = hard lumps, 4–5 = ideal, 7 = watery)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	63	1–2	3–4	60–180	15–30	1–2	0	None	None	Moderately dissatisfied	Somewhat satisfied	2	4
2	25	1–2	3–4	15–30	15–30	0	0	One time	None	Somewhat satisfied	Somewhat satisfied	2	4
3	63	2–3	3–4	60–180	30–60	5–6	0	Everytime	None	Moderately dissatisfied	Somewhat satisfied	1	4
4	43	1–2	3–4	60–180	30–60	≥7	0	Everytime	A few times	Moderately dissatisfied	Somewhat satisfied	2	4
5	50	5–6	5–6	60–180	30–60	1–2	0	Everytime	Everytime	Almost Fully satisfied	Fully satisfied	4	4
6[a]	10[a]	3–4	–	30–60	–	1–2	–	None	–	Moderately dissatisfied	–	5	–
7	60	≥7	5–6	60–180	30–60	1–2	0	Everytime	Most times	Moderately dissatisfied	Somewhat satisfied	6	4
8	60	3–4	3–4	15–30	15–30	3–4	1–2	Everytime	Most times	Almost Fully satisfied	Fully satisfied	2	5
9	60	3–4	≥7	5–15	5–15	0	0	Everytime	A few times	Somewhat satisfied	Somewhat satisfied	2	4
10	60	≥7	5–6	60–180	60–180	3–4	3–4	A few times	None	Almost Fully satisfied	Somewhat satisfied	6	6
11	36	3–4	3–4	30–60	30–60	0	1–2	One time	Everytime	Almost Fully satisfied	Almost Fully satisfied	6	5

[a]Participant #6 was lost to follow up due to early withdrawal from the study after ten sessions of EAW training

Some of our findings are similar to those of Hubscher et al. who evaluated changes in bowel function after BWSTT and found a significantly decreased time required for defecation after BWSTT. They also evaluated frequency of defecation and frequency of fecal incontinence, as well as medication and laxative usage, but did not find statistically significant changes for these items [13]. The most important distinction to make between BWSTT and EAW is that EAW is weight-bearing like walking in non-paralyzed individuals [29] whereas BWSTT unweights the individual during walking. Trends observed in our case series were also consistent with trends of improved incontinence, constipation, as well as time and assistance needed for bowel management, described in more recent studies performed using other EAW devices [24, 25].

In the general population, walking has been recognized to stimulate the GI tract by increasing colonic motility in various ways [7–9]. Walking has been shown to increase intragastric pressures via abdominal muscle contraction (as shown after 15 min of walking at 1.57 m/s at 0–12% inclines) [11]. Long-term physical inactivity has also been shown to cause constipation even in otherwise healthy individuals [36]. Four studies reported by Gao et al. showed significant improvements in constipation after walking interventions that ranged in duration from 4–12 weeks compared to usual care, normal lifestyle, herbal medications and acupuncture [37]. Furthermore, bowel dysfunction in various levels of SCI has been associated with varying delays in colonic transit time, difficulties in increasing intraabdominal pressure, and absences of anal resistance or external anal sphincter contraction [38]. In other words, the inability to walk secondary to SCI may additionally result in motility dysfunction of the gastrointestinal tract possibly because the gastrointestinal tract can detect and respond to the movement of walking itself, or to its absence, in persons with SCI.

Use of an exoskeleton places several demands on the neuromuscular system. The user must learn to execute controlled trunk movements to provide weight shifts for step initiation and balance maintenance. This activates back and abdominal muscles. Second, the user must control the crutches and achieve stability by activating upper extremity and chest muscles. Third, the user must coordinate all of these movements, shifting weights and placing crutches, with correct timing and force. The exoskeletal device used in this study required concerted activation of the entire upper body's musculature, making it suitable for persons with T1 paraplegia and below. Although nearly half of our participants had T5 paraplegia and above, in which case the activation of back or abdominal musculature may not have played as large of a role, the activation of upper extremity and chest muscles, as well as the need to coordinate all movements, would still apply. Overall, for those with

Table 3 Spinal cord injury—quality of life (SCI-QOL) bowel management difficulties short form scores pre- and post-exoskeletal-assisted walking (EAW)

ID	# EAW sessions completed	Raw score Pre-EAW training	Raw score Post-EAW training	Scaled score Pre-EAW training	Scaled score Post-EAW training	% SCI-QOL score change from baseline	Clinically significant difference between pre- and post-EAW?
1	63	14	9	51	39	23.5	Yes
2	25	19	18	56	55	1.8	No
3	63	41	9	69	39	43.5	Yes
4	43	37	19	66	56	15.2	Yes
5	50	13	11	50	47	6.0	No
6[a]	10	30	–	62	–	–	–
7	60	41	10	69	45	34.8	Yes
8	60	24	13	59	50	15.3	Yes
9	60	15	9	52	39	25.0	Yes
10	60	26	17	60	54	10.0	Yes
11	36	14	21	51	57	−11.8	Yes[b]

Higher scores indicate higher levels of difficulty and poorer levels of quality of life as related to bowel function in persons with spinal cord injury

[a]Participant #6 was lost to follow up due to early withdrawal from the study after ten sessions of EAW training

[b]Participant #11 reported clinically significant difference but score worsened after EAW training

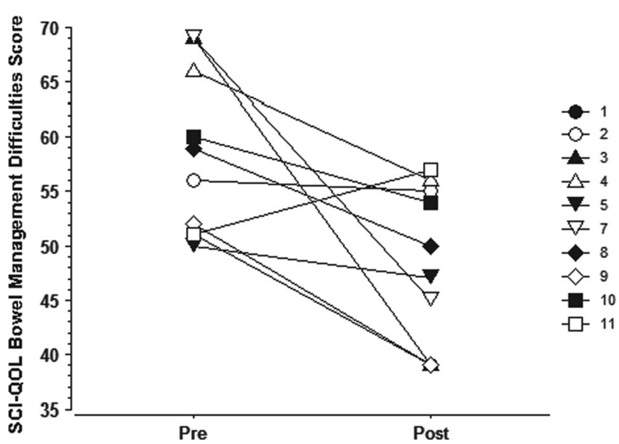

Fig. 2 Spinal Cord Injury—Quality Of Life (SCI-QOL) bowel management difficulties short form scores pre- and post-exoskeletal-assisted walking (EAW)

nonambulatory paraplegia, EAW could potentially serve as a dynamic, upright, over ground activity, stimulating bowel function in a way analogous to walking.

Limitations of this study include a small sample size ($N = 10$) and that the improvements observed in this small cohort were not uniform. Furthermore, we were not able to eliminate the variation in EAW training time and session numbers due to logistical barriers such as patients who suddenly had changes in availability or difficulties with transportation. We also asked participants to avoid changes in diet or medication regimens during the course of the study but such restrictions could not be strictly enforced or monitored in the outpatient setting. Finally, our findings cannot be generalized because our study was in the end not a randomized clinical trial.

Despite the appreciated limitations of this study, our preliminary findings are suggestive of a potential benefit of EAW training on bowel function after SCI that are certainly worthy of further investigation. Additional studies with more participants using a controlled design would be anticipated to provide further understanding and confirmation of this observation. Such investigations would also benefit from collecting additional data from other bowel function measures validated in SCI populations such as the Wexner Scale [38]. Other populations with immobilization and associated difficulty with bowel evacuation may potentially also benefit from upright walking activity, such as EAW, if deemed safe and applicable.

Conclusion

Post-EAW training, at least half of our participants with SCI reported an improvement in some aspect of their bowel management, bowel function and/or QOL related to bowel function when compared to baseline. These preliminary findings suggest that EAW in persons with SCI, by serving as an upright over ground exercise modality analogous to normal walking, may have the potential to improve bowel function, bowel management and related QOL measures and is worthy of further study.

Data archiving

The data generated and analyzed during the current study are available from the corresponding author upon reasonable request. For access to more detailed measures with regard to the 9-item SCI-QOL Bowel Management Difficulties Short Form, readers are encouraged to request access directly from the authors of the original source manuscript by sending an e-mail to Dr. David Tulsky and Pamela Kisala at SCI-QOL@udel.edu or in REDCap for use free of charge.

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Author contributions AC: Data analysis. Interpretation of the data. Drafting of the manuscript. PKA: Planning and conducting the study. Collecting data. SKn: Planning and conducting the study. Collecting data. SKo: Planning and conducting the study. Collecting data. WAB: Planning and conducting the study. Drafting of the manuscript. MAK: Planning and conducting the study. Drafting of the manuscript. NYH: Conducting study. Drafting of the manuscript. VH: Drafting of the manuscript. AMS: Planning and conducting the study. Data analysis. Interpretation of data. Drafting of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Statement of ethics We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

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