

# Factors Associated with Recovery in Motor Strength, Walking Ability, and Bowel and Bladder Function after Traumatic Cauda Equina Injury

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## Abstract

Traumatic cauda equina injury (TCEI) is usually caused by spine injury at or below L1 and can result in motor and/or sensory impairments and/or neurogenic bowel and bladder. We examined factors associated with recovery in motor strength, walking ability, and bowel and bladder function to aid in prognosis and establishing rehabilitation goals. The analysis cohort was comprised of persons with acute TCEI enrolled in the Rick Hansen Spinal Cord Injury Registry. Multi-variable regression analysis was used to determine predictors for lower-extremity motor score (LEMS) at discharge, walking ability at discharge as assessed by the walking subscores of either the Functional Independence Measure (FIM) or Spinal Cord Independence Measure (SCIM), and improvement in bowel and bladder function as assessed by FIM-relevant subscores. Age, sex, neurological level and severity of injury, time from injury to surgery, rehabilitation onset, and length of stay were examined as potential confounders. The cohort included 214 participants. Median improvement in LEMS was 4 points. Fifty-two percent of participants were able to walk, and >20% recovered bowel and bladder function by rehabilitation discharge. Multi-variable analyses revealed that shorter time from injury to rehabilitation admission (onset) was a significant predictor for both improvement in walking ability and bowel function. Longer rehabilitation stay and being an older female were associated with improved bladder function. Our results suggest that persons with TCEI have a reasonable chance of recovery in walking ability and bowel and bladder function. This study provides important information for rehabilitation goals setting and communication with patients and their families regarding prognosis.

**Keywords:** bowel and bladder; motor score; spinal cord injury; traumatic cauda equina injury; walking

## Introduction

**T**RAUMATIC CAUDA EQUINA INJURY (TCEI) results from compression or damage to the lumbosacral nerve roots of the cauda equina. Cauda equina syndrome (CES) is a relatively uncommon clinical syndrome after traumatic spine injury typically at or below L1, representing only 5% of all cases of spine trauma.<sup>1,2</sup> CES encompasses a complex constellation of symptoms and signs that can

include low back pain, uni- or bilateral radicular pain in the sciatic-innervated territory, flaccid lower extremity weakness, and sensory impairment, including the perineum and, classically, areflexic bowel and/or bladder.<sup>3,4</sup> It is most commonly caused by a lumbar disc herniation, occurring in ~2% of cases of herniated lumbar disc and requires emergency spinal surgical intervention.<sup>3</sup> Not all TCEIs develop the complete clinical syndrome, and variable motor and sensory deficits can be observed.

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Non-operative treatment may be indicated for stable TCEI without significant neurological deficit or instability of the spine, provided that the patient can tolerate conservative treatment and external immobilization. Operative management of unstable thoracolumbar fractures with potential for significant neurological compromise is recommended.<sup>1</sup> Surgical neural decompression and spine stabilization are often used to correct reduced spinal canal diameter associated with TCEI,<sup>5</sup> and decompression is thought to facilitate motor and bladder recovery.<sup>6,7</sup> Although there is no reported evidence of deleterious effects resulting from early surgery, there are inconsistent findings regarding the benefits in TCEI,<sup>8–10</sup> in contrast to the widely reported evidence of improved outcomes in early surgical decompression subsequent to cervical spinal cord injury (SCI).<sup>11,12</sup> However, there is evidence in the non-traumatic CES literature that surgery performed more than 48 h post-injury leads to worse outcomes.<sup>13</sup>

In addition to motor and sensory improvement, recovery of bowel and bladder function is a top priority for those living with SCI<sup>14</sup> and is associated with a person's independence and quality of life.<sup>15</sup> Explanatory models of recovery in motor strength and ability to walk, as well as bowel and bladder function, would be very useful to help guide management, establish realistic rehabilitation goals, and anticipate prognosis and outcomes when communicating with patients and their family members. This study was undertaken to examine factors associated with improvement in lower-extremity motor scores (LEMSs), as well as recovery in ability to walk and bowel and bladder function after TCEI.

## Methods

### Study design

The study utilized data collected from enrolled participants in the Rick Hansen Spinal Cord Injury Registry (RHSCIR) from July 2004 to February 2017. The RHSCIR prospectively enrolls adults admitted with a new acute spine trauma with SCI to any of the participating 18 acute and 13 rehabilitation facilities across Canada. The registry was initiated in 2004 to answer *a priori* research questions and facilitate implementation of best practices. All RHSCIR sites obtained local research ethics board approval before enrolling participants, and data-sharing agreements were in place with each site. A core data set is collected on all RHSCIR participants, and a detailed data set is collected on participants who can be approached during their hospital stay and provide informed consent. For the purposes of this study, only participants who had a final complete registry record were included in the analysis. Details on the RHSCIR data set have been described elsewhere.<sup>16</sup>

### Analysis cohort

The study cohort included persons identified as having cauda equina injuries (i.e., lower motor neuron injuries attributable to damage to nerve roots below the conus medullaris level) at admission, with any degree of neurological impairment after spine trauma (American Spinal Injury Association Impairment Scale [AIS] A to D) and single neurological level of injury (NLI) from L1 to S3 at admission to a RHSCIR acute facility, as assessed using the International Standards for the Neurological Classification of Spinal Cord Injury (ISNCSCI).<sup>17</sup>

### Study variables

Baseline factors included age, sex, and pre-existing medical comorbidities at the time of injury based on the Charlson Comorbidity Index.<sup>18</sup> Injury factors included mechanism of injury and neurological parameters, including injury severity (AIS A, B, C, or D), NLI (L1, L2, or L3–S3), and voluntary anal contraction (VAC;

present, absent) obtained from an ISNCSCI examination at acute admission. These groupings of NLI were determined by clinical expertise and number of cases in each cell in the contingency table. Management factors included time from injury to arriving at a RHSCIR acute facility (hours), surgical or non-surgical treatment of the spine trauma, and, where applicable, time from injury to surgery (hours) and surgical approach (anterior, posterior, anterior and posterior). Acute and rehabilitation lengths of stay (LOSs) and rehabilitation onset (time from injury to admission to rehabilitation care) were also reported.

### Outcome variables

Outcome measures of the study were motor score, and recovery in walking ability, and bowel and bladder function. Motor score outcome was defined by both lower-extremity motor score (LEMS) at discharge and improvement in LEMS between acute admission and discharge from care (i.e., from acute if not attending rehabilitation or from rehabilitation for those attending). The LEMS is obtained from the ISNCSCI examination and has a maximum score of 50. Recovery in the walking ability was defined as regaining walking ability at discharge as assessed using the Functional Independence Measure (FIM®)\* and the Spinal Cord Independence Measure (SCIM III<sup>19</sup>). Ability to walk was considered for a score of 6 or 7 (modified/complete independence) on the FIM “locomotion” item for those who reported “walk” or “both” as the locomotion mode or a SCIM score of 4–8 (4, walks with a walking frame or crutches [swing]; 5, walks with crutches or two canes [reciprocal walking]; 6, walks with one cane; 7, needs leg orthosis only; and 8, walks without walking aids) on the SCIM “mobility for moderate distances” item. Using both FIM and SCIM data was to increase the sample size, and these items have been mapped for their equivalency.<sup>20</sup>

Recovery in bowel and bladder function was defined as improvement in respective bowel and bladder score in the FIM “sphincter control” subscore between rehabilitation admission and discharge. A score <7 in the FIM “sphincter control” subscore was also used to describe dysfunction or dependence in the management of bowel and bladder. Only FIM was used because the equivalency of the SCIM has yet to be validated with the FIM on sphincter control.

For greater clarity, data on LEMS and VAC were collected upon admission to a RHSCIR acute facility and again at discharge from care, which could be from acute if not attending rehabilitation or from rehabilitation if attending, but not both. For FIM data, patients who did not attend rehabilitation had their FIM data collected upon acute discharge only and therefore cannot be used to calculate change in FIM scores; those who attended rehabilitation had both FIM and SCIM data collected at admission and discharge. No SCIM data were collected at acute discharge.

### Statistical analysis

Descriptive statistics were used to describe the demographics, number of comorbidities, mechanism of injury, and management strategies in the cohort. Bivariate analysis was performed to compare the outcome variables between patients with different neurological injury (AIS A/B vs. AIS C/D; L1 vs. L2 vs. L3–S3) to determine associations between injury and outcomes of interest. Bivariate analysis was also performed comparing patients who had early rehabilitation onset and those who had late onset using the median rehabilitation onset (24 days) as a cutoff to explore for any potential sampling bias. The groups were compared using either *t*-test (analysis of variance for more than two categories) or Wilcoxon rank-sum test (Kruskal-Wallis' test for more than two categories) for normally distributed versus non-normally

\*FIM® instrument (FIM); FIM® is a trademark of the Uniform Data System for Medical Rehabilitation, a division of UB Foundation Activities, Inc.

distributed continuous variables, respectively. To determine correlation between VAC and recovery in bowel and bladder function, two comparisons were performed: Patients who had VAC at acute admission were compared to those with no reported VAC, and patients who had gained VAC by discharge from care were compared to those who still did not have VAC. Comparisons between the two categorical variables were assessed using a chi-square test (or Fisher's exact test if the expected cell counts were five or less). Sensitivity analysis was conducted to examine any discrepancy between patients who had data on change in bowel and bladder score and those who had missing data.

Multi-variable analysis was performed to determine factors associated with the outcomes of interest (walking ability using logistic regression; LEMS at discharge and bowel and bladder function recovery using linear regression). Factors examined were age at time of injury, sex, neurological injury severity, NLI, time from injury to surgery, rehabilitation onset, and rehabilitation LOS; in addition, LEMS at acute admission was also included for LEMS at discharge and VAC at acute admission for bowel and bladder function recovery. Step-wise variable selection methods ( $p$  values for a variable to enter and stay in the model set to 0.30 and 0.10, respectively) were applied to all regression models. A final model for each outcome obtained had included the significant predictors from step-wise variable selection, as well as injury severity, NLI, and time from injury to surgery, given that these variables were deemed clinically relevant regardless of their significance.

Patients who had complete data on the variables considered were included in the multi-variable analysis, except for the model for walking ability where patients who were walking at rehabilitation admission were excluded from the model given that the goal was to determine factors for walking recovery. Goodness-of-fit tests were performed for all models, and the Akaike Information Criterion was used for model selection. Associations with a  $p$  value  $<0.05$  were considered statistically significant. All analyses were performed using SAS software (Version 9.4 of the SAS System for Windows, copyright © 2013; SAS Institute Inc., Cary, NC).

## Results

### Analysis cohort

The RHSCIR included 4370 persons with NLI data available, of whom 214 met the inclusion criteria upon admission to acute care at a RHSCIR facility. The majority of the persons in this cohort were males with a mean age of 40 years who mostly sustained a high-lumbar, but less-severe, TCEI that required surgical treatment (Table 1).

### Recovery in motor strength

The median change in LEMS from admission to discharge was an increase of 4 points (Supplementary Table S1). Patients with an L1 injury level achieved the greatest improvement in LEMS from admission to discharge compared to the other two groups ( $p < 0.0001$ ; Supplementary Table S2). However, when looking at the absolute score both at admission and at discharge, patients with an L2 or L3–S3 injury had significantly higher LEMS than the L1 group ( $p < 0.0001$ ), indicating that patients with L2–S3 injury had more preserved motor function. Similarly, patients with AIS C/D injuries had significantly higher LEMS at admission and at discharge compared to those with AIS A/B injuries ( $p < 0.0001$ ), even though the change in LEMS was similar between the two groups (Table 2). Given this, LEMS at discharge was selected to be used as the outcome for the multi-variable analysis. Older age ( $p = 0.04$ ) and higher LEMS at acute admission ( $p < 0.0001$ ) were found to be significantly associated with greater LEMS at discharge from care in the linear regression analysis that was adjusted for injury characteristics (severity and level) and time to

TABLE 1. PATIENT CHARACTERISTICS OF THE STUDY COHORT ( $n = 214$ )

Variables	Study cohort ( $n = 214$ )	Available
Age at injury, years; mean (SD)	39.9 (17.3)	214
Range	16–84	
Male sex; $n$ (%)	164 (76.6)	214
Comorbidities; $n$ (%)		66
None	26 (39.4)	
One	29 (43.9)	
Two or more	11 (16.7)	
Mechanism of injury; $n$ (%)		209
Fall	102 (48.8)	
Transport	58 (27.7)	
Sports	30 (14.4)	
Others	19 (9.01)	
Neurological injury severity at acute admission; $n$ (%)		207
AIS A	48 (23.2)	
AIS B	30 (14.5)	
AIS C	39 (18.8)	
AIS D	90 (43.5)	
Neurological level of injury at acute admission; $n$ (%)		214
L1	103 (48.1)	
L2	62 (29.0)	
L3–S3	49 (22.9)	
Voluntary anal contraction at acute admission; $n$ (%)		188
Present	94 (50.0)	
Absent	94 (50.0)	
Time from injury to RHSCIR acute facility (h); median (IQR)	8.5 (21.5)	196
Had surgery; $n$ (%)	184 (97.4)	189
Time from injury to surgery (h); median (IQR)	26.5 (53.0)	162
$\leq 24$ h; $n$ (%)	79 (48.8)	
$> 24$ h; $n$ (%)	83 (51.2)	
Type of approach; $n$ (%)		129
Anterior	11 (8.5)	
Posterior	114 (88.4)	
Mixed	4 (3.1)	
Acute length of stay (days); median (IQR)	19.0 (19.0)	206
Attended rehabilitation; $n$ (%)	155 (72.4)	214
Rehabilitation onset (days); median (IQR)	24.0 (24.0)	158
Rehabilitation length of stay (days); median (IQR)	58.0 (50.0)	155

SD, standard deviation; AIS, American Spinal Injury Association Impairment Scale; RHSCIR, Rick Hansen Spinal Cord Injury Registry; IQR, interquartile range.

surgery (Table 2). Age at the time of injury was positively correlated with both LEMS at admission and LEMS at discharge, suggesting that older persons were more likely to have higher LEMS at both time points ( $p = 0.02$  and  $p = 0.007$ , respectively), which is consistent with the results of the adjusted regression analysis.

### Recovery of the ability to walk

At admission to rehabilitation, 10% reported to be able to walk (Supplementary Table S1). At discharge, 52% of patients were able

TABLE 2. A MULTIPLE LINEAR REGRESSION FOR MODELING LEMS AT DISCHARGE (*n* = 105)

<i>Outcome: LEMS at discharge from care</i>					
<i>Variable</i>	<i>Estimate</i>	<i>Standard error</i>	<i>95% confidence interval</i>		<i>p value</i>
Intercept	11.42	5.38	0.77	22.11	0.0359
Age at injury	0.12	0.06	0.01	0.23	<b>0.0363</b>
Neurological injury severity at acute admission					
AIS A/B	-3.45	2.32	-8.05	1.14	0.1393
AIS C/D	Baseline	—	—	—	—
Neurological level of injury at acute admission					
L1	1.10	3.54	-5.91	8.12	0.7555
L2	-1.23	2.78	-6.74	4.28	0.6585
L3-S3	Baseline	—	—	—	—
LEMS at acute admission	0.66	0.09	0.47	0.85	<b>&lt;0.0001</b>
Time from injury to surgery	0.00	0.00	-0.00	0.00	0.8245

*p* value in bold indicates statistical significance.

LEMS, lower-extremity motor score; AIS, American Spinal Injury Association Impairment Scale; L, lumbar; S, sacral.

to walk. Not surprisingly, patients with less-severe injuries were more likely to walk at discharge compared to those with more-severe injuries (64% AIS C/D vs. 36% AIS A/B, *p* = 0.0012; 89% L3-S3 vs. 35% L1, *p* < 0.0001). In a model using logistic regression, shorter rehabilitation onset (i.e., going to rehabilitation sooner) was found to be significantly associated with walking ability at discharge from rehabilitation (*p* = 0.0008; Table 3). As in the bivariate analysis, patients with more-severe injuries (AIS A/B and L1 injuries) were also found to be less likely to walk at discharge in the multi-variable model.

*Recovery of bowel and bladder function*

Of the 155 patients who attended rehabilitation where FIM was collected upon admission and before discharge, 92 had bowel and bladder data available to calculate the change in score. Based on the

sensitivity analysis, patients with available data were significantly younger (*p* = 0.02) and more likely to have an L1 injury level (*p* = 0.001) than those with missing data. There were no significant differences with regard to sex, time from injury to a RHSCIR acute facility, time from injury to surgery, rehabilitation onset, or LOS in the acute and rehabilitation settings.

Of the 87 patients with bowel dysfunction at rehabilitation admission, 24% had recovery (FIM = 7 on bowel subscore) at discharge (Supplementary Table S3). Similarly, of the 81 patients with bladder dysfunction at rehabilitation admission, 22% had recovery (FIM = 7 on bladder subscore) at discharge. Median change in both bowel and bladder score from admission to discharge was an increase of 4 points (Supplementary Table S1). Patients with AIS C/D had a significantly higher bowel score at admission and subsequently a smaller change than those with AIS A/B given the ceiling effect of FIM (Supplementary Table S1). Similar trends were observed for bladder score, where patients with AIS C/D had significantly higher bladder scores at admission and discharge (Supplementary Table S1). No correlation was found between injury level and change in bowel and bladder score (Supplementary Table S2).

In terms of correlation between change in bowel and bladder scores and VAC, patients with VAC at admission had significantly higher bowel and bladder scores at admission than those without VAC (Supplementary Table S4). These patients with VAC had an accordingly significantly smaller gain in bowel and bladder scores than patients without VAC (Supplementary Table S4). Three patients who had VAC at admission had reportedly lost their VAC at discharge. Analyzing only patients who had no VAC at admission, those who recovered VAC by discharge had similar bowel and bladder scores to those who did not recover VAC (Supplementary Table S5).

When determining the factors associated with improved change in bowel score, earlier rehabilitation onset was found to be the only significant predictor for more improvement (*p* = 0.005) after adjusting for injury characteristics and time to surgery (Table 4). As for improvement in bladder score, patients who are older (*p* = 0.008), females (*p* = 0.03), and had a longer rehabilitation LOS (*p* = 0.001), were more likely to have more improvement in bladder score (Table 5). Age at injury was positively associated with bladder score, in that patients ≥ 60 years of age had lower bladder scores at admission and, hence, more room for change than those younger (median 1.0 vs. 3.0; *p* = 0.04), which suggests a greater ceiling effect among younger persons. A similar trend was

TABLE 3. A LOGISTIC REGRESSION ANALYSIS OF WALKING ABILITY AT DISCHARGE (*n* = 99)

<i>Outcome: Walking ability at rehabilitation discharge</i>						
<i>Variable</i>	<i>Estimate</i>	<i>Standard error</i>	<i>Odds ratio</i>	<i>95% confidence interval</i>		<i>p value</i>
Intercept	3.89	1.01				0.0001
Neurological injury severity at acute admission						
AIS A/B	-1.34	0.53	0.26	0.09	0.73	<b>0.0108</b>
AIS C/D	Baseline	—	—	—	—	—
Neurological level of injury at acute admission						
L1	-2.05	0.85	0.13	0.02	0.68	<b>0.0160</b>
L2	-0.74	1.03	0.48	0.06	3.59	0.4712
L3-S3	Baseline	—	—	—	—	—
Time from injury to surgery	0.00	0.00	1.00	1.00	1.00	0.9935
Rehabilitation onset	-0.07	0.02	0.94	0.90	0.97	<b>0.0008</b>

*p* value in bold indicates statistical significance.

AIS, American Spinal Injury Association Impairment Scale; L, lumbar; S, sacral.

TABLE 4. A MULTIPLE LINEAR REGRESSION FOR MODELING IMPROVEMENT IN BOWEL SCORE ( $n=76$ )

Outcome: Improvement in bowel score between rehabilitation admission and discharge

Variable	Estimate	Standard error	95% confidence interval		p value
Intercept	3.91	1.03	1.86	5.97	0.0003
Neurological injury severity at acute admission					
AIS A/B	0.29	0.83	-1.35	1.94	0.7232
AIS C/D	Baseline	—	—	—	—
Neurological level of injury at acute admission					
L1	0.36	0.68	-0.99	1.71	0.5968
L2	0.95	0.83	-0.70	2.60	0.2549
L3-S3	Baseline	—	—	—	—
Voluntary anal contraction at acute admission					
Present	-1.61	0.88	-3.37	0.14	0.0707
Absent	Baseline	—	—	—	—
Time from injury to surgery	0.00	0.00	0.00	0.00	0.2837
Rehabilitation onset	-0.02	0.01	-0.04	-0.01	<b>0.0048</b>

*p* value in bold indicates statistical significance.

AIS, American Spinal Injury Association Impairment Scale; L, lumbar; S, sacral.

observed for bowel scores, even though the difference between the older and younger groups did not reach significance.

#### Effect of rehabilitation onset

To test whether the results of rehabilitation onset are confounded by potential sample-group imbalance, patients who were admitted to rehabilitation within 24 days, which is the median (early), were compared to those admitted after (later). The “early” group had fewer patients with L1 injuries (50% vs. 66%) and more patients with L3-S3 injuries (27% vs. 8%;  $p=0.007$ ) than the “later” group. The “early” group also had shorter rehabilitation LOS than the “later” group (51 vs. 65 days;  $p=0.03$ ). There were no significant differences with regard to age, sex, counts of comorbidities, injury severity, time from injury to a RHSCIR acute facility, and surgery status.

## Discussion

### Diagnosis of cauda equina injury

TCEI clinically refers to a traumatic injury of the neural elements below the conus medullaris and is commonly located at or below the L1-L2 disc level. Based on magnetic resonance imaging (MRI) data in adults, the conus medullaris terminates between the lower third of the T12 and the lower third of the L2 vertebrae in 95% of persons.<sup>1,21,22</sup> Imaging (computed tomography [CT] and MRI) remains the gold standard for investigation of suspected thoracolumbar spinal trauma<sup>1,23-25</sup> given that these techniques allow determination of spinal canal diameter and visualization of neural structures, enabling better anatomical differentiation be-

TABLE 5. A MULTIPLE LINEAR REGRESSION FOR MODELING IMPROVEMENT IN BLADDER SCORE ( $n=76$ )

Outcome: Improvement in bladder score between rehabilitation admission and discharge

Variable	Estimate	Standard error	95% confidence interval		p value
Intercept	-0.02	1.29	-2.60	2.56	0.9871
Age at injury	0.04	0.01	0.01	0.07	<b>0.0077</b>
Sex					
Female	1.24	0.56	0.12	2.35	<b>0.0303</b>
Male	Baseline	—	—	—	—
Neurological injury severity at acute admission					
AIS A/B	0.62	0.84	-1.05	2.30	0.4602
AIS C/D	Baseline	—	—	—	—
Neurological level of injury at acute admission					
L1	-1.04	0.70	-2.45	0.36	0.1436
L2	-0.15	0.84	-1.84	1.53	0.8584
L3-S3	Baseline	—	—	—	—
Voluntary anal contraction at acute admission					
Present	-0.31	0.89	-2.10	1.48	0.7286
Absent	Baseline	—	—	—	—
Time from injury to surgery	0.00	0.00	0.00	0.00	0.5922
Rehabilitation length of stay	0.02	0.01	0.01	0.04	<b>0.0013</b>

*p* value in bold indicates statistical significance.

AIS, American Spinal Injury Association Impairment Scale; L, lumbar; S, sacral.

tween cauda equina and conus medullaris injury. In the absence of imaging data, in our study, only patients with LI and caudal NLI were included to avoid mixing conus medullaris and cauda equina injuries given that these are clinically and pathologically different syndromes; patients with injury to the cauda equina have symptoms consistent with lower motor neuron injury attributable to lumbosacral nerve root involvement. To our knowledge, this study includes the largest cohort of persons where best efforts have been made to isolate cauda equina injury.

Although outcomes of SCI have been studied and reported extensively in the literature, relatively less has been documented on TCEI. Because of the anatomical and physiological differences between the spinal cord and cauda equina, it is unsuitable to extrapolate conclusions from studies of traumatic SCI. Our motivation thus is contributing to the knowledge on TCEI, by investigating the clinical patterns and factors associated with the functional outcomes of injuries of the cauda equina.

### Management of traumatic cauda equina injury

The benefit of early surgery in lumbar spine fracture in the presence of neurological deficit is not well defined in the literature, and there is no standard of care regarding optimal timing of surgery in patients with TCEI. However, it is recommended that surgery be performed as soon as the patient is medically stable given that early

surgery may have the advantages of allowing early mobilization and reducing complications such as pain.<sup>1,8</sup>

In our study, time from injury to surgery was not correlated with recovery of motor strength, the ability to walk, or bowel or bladder function, which is consistent with previous studies.<sup>8–10</sup> Early surgical treatment may not be as beneficial in patients with TCEI as compared to those with cervical and thoracic SCI, where early surgical decompression of the spinal cord was found to be safe and may improve neurological recovery after acute traumatic SCI.<sup>12,26</sup> In our cohort, >60% had less-severe neurological injury, which could explain the finding of delayed surgery (>24 h) in 51% of the patients.

#### *Predictors of recovery in traumatic cauda equina injury*

Studying the predictors of outcomes after TCEI has proved challenging because of the uniqueness and heterogeneity of TCEI, with variable degrees of injury severity from mild neurological deficits to severe complete cauda equina injury.<sup>9</sup> However, there are important advantages in identifying predictors of outcomes after TCEI; a more informed prognosis can facilitate interprofessional communication, patient education, and setting realistically rehabilitation goals. Our results showed that earlier rehabilitation onset was a significant predictor for recovery in the ability to walk and improvement in bowel score after adjusting for injury severity, level of injury, and time of surgery. The association between early rehabilitation onset and improved functional outcome has also been found in previous studies.<sup>27,28</sup>

Interestingly, longer length of rehabilitation stay, older age, and being female were associated with improved bladder score. The effect of these predictors on bladder score requires further evaluation. For motor strength recovery, older age and higher LEMS at admission were significantly associated with higher LEMS at discharge from care. The observation that older age was associated with better motor outcome could partially be explained by the fact that persons in this demographic are less exposed to high-impact mechanisms of injury and thus maintain higher LEMS at admission than younger patients. Further, with a less-severe injury, older patients would also be likely to make more-significant improvement in bladder scores than the younger persons despite a low bladder score at admission. It remains to be determined why a similar effect was not observed in the bowel recovery.

#### *Prognosis after traumatic cauda equina injury*

Improving bowel and bladder dysfunction after TCEI is of key importance to affected persons. Despite the current advanced management of spinal injuries including TCEI, many patients are still left with mobility impairment and bowel and bladder dysfunction; 52% of our study cohort were able to walk by discharge, but significant improvement of bowel and bladder function was noted in only 24% and 22%, respectively. Interestingly, 40% of patients recovered VAC despite that only 24% had functional bowel recovery. However, it is encouraging that the median of bowel and bladder score at discharge was 6 for our study cohort, even for subgroups (AIS A/B; L1) with a very low score upon admission, and that the NLI did not influence the chance of bladder and bowel functional recovery. Importantly, our multi-variable analysis results, demonstrating that the sooner patients are admitted to a spinal rehabilitation center the better their recovery in walking ability and bowel function, support the importance of rehabilitation of these injuries.

Other than a few studies on thoracolumbar injuries, most of the data used for prognostication of TCEI are derived from degenerative spinal diseases data.<sup>29</sup> Rahimi-Movaghar and colleagues reported that bladder recovery was observed in 64% of patients and nerve root recovery in 83% of patients<sup>30</sup>; McAfee and colleagues reported that 14 of 30 patients unable to walk before surgery regained full independence in walking, and 12 of 32 patients demonstrated bowel and bladder recovery,<sup>6</sup> although it is difficult to compare these studies with ours given that both conus medullaris and cauda injuries were included in their cohorts.

#### *Study limitations*

CT/MRI is the gold standard for confirming TCEI and differentiating it from conus medullaris injury. However, imaging information is not collected in the RHSCIR data set; thus, NLI as determined by the ISNCSCI was used to classify patients as having TCEI; as such, some patients in our cohort may have been mistakenly assigned as having TCEI.

Although the sample size in our study was larger than earlier studies done on TCEI,<sup>6,30</sup> missing data were a challenge. Two of the main outcomes of interest, the bowel and bladder recovery, were especially affected by missing data. Those who had data on bowel and bladder function were younger and more frequently had an NLI of L1; given that persons with a higher level of injury have a greater capacity for recovery, this may confound the results.

Another challenge was the outcome measures and their timing. Bowel and bladder function were assessed by FIM, which is a measure of the patient's independence in managing their bowel and bladder function and not of the neurological function of the bowel and bladder. In terms of timing, recovery was determined by the change in FIM score between rehabilitation admission and discharge because FIM scores were not collected during acute care, so any improvement post-surgery or before rehabilitation was not captured. Further, the "end point" for this study was at discharge from rehabilitation, but recovery can potentially continue months after discharge.<sup>31</sup> This might have particularly limited the interpretation of the results on the correlation between gaining VAC and bowel and bladder function (Supplementary Table S5).

#### *Future work*

Despite the limitations of this observational study, it has provided a description of the clinical patterns and outcome predictors for patients with TCEI, which, hopefully, will stimulate further research looking at this unique type of spinal injury. More important, effort in ensuring the standardized collection of data on patient-centered outcomes (e.g., bowel and bladder function) is needed given that high-quality data will enable more in-depth analysis and further understanding. Such studies include investigation of conus medullaris injury, as well as prospective trials for patients with TCEI, to examine the role of surgical management on recovery.

#### **Conclusion**

Persons with TCEI have a reasonable chance of recovery in the ability to walk and bowel and bladder function, with one quarter achieving full bowel and bladder functional independence, and one half being able to walk on hospital discharge. This information is useful for clinicians to prognosticate and communicate with patients and their families.

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## Author Disclosure Statement

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