The Impact of Age on Mortality, Impairment, and Disability among Adults with Acute Traumatic Spinal Cord Injury

Julio C. Furlan^{1,2} and Michael G. Fehlings^{1,3,4}

Abstract

Given the potential effects of age on mortality, impairment, and disability among individuals with traumatic spinal cord injury (SCI), we examined these issues using a large, prospectively accrued clinical database. This study includes all patients who were enrolled in the Third National Spinal Cord Injury Study (NASCIS 3). Motor, sensory, and pain outcomes were assessed using NASCIS scores. Functional outcome was evaluated using the Functional Independence Measure (FIM). Data analyses included regression models adjusted for major potential confounders (i.e., sex, ethnicity, Glasgow Coma Scale [GCS] score, blood alcohol concentration on admission, drug protocol, cause, and level and severity of SCI). Mortality rates among older people (≥ 65 years) were significantly greater than those of younger individuals at 6 weeks, at 6 months, and at 1 year following SCI (38.6% versus 3.1%; $p < 0.0001$). Among survivors, age was not significantly correlated with motor recovery or change in pain scores in the acute and chronic stages after SCI based on regression analyses adjusted for major confounders. However, older individuals experienced greater functional deficit (based on FIM scores) than younger individuals, despite experiencing similar rates of sensorimotor recovery (based on NASCIS scores). Our results suggest that older individuals have a substantially increased mortality rate during the first year following traumatic SCI in comparison with younger patients. Among survivors, the potential of older patients with SCI to neurologically improve within the first year post-injury does not appear to translate into similar functional recovery compared to that seen in younger individuals. Given this fact, rehabilitation protocols that are more focused on functional recovery may reduce disability among older people with acute traumatic SCI.

Key words: aging; functional recovery; mortality; motor recovery; spinal cord injury

Introduction

THE NUMBER OF ELDERLY PEOPLE WORLDWIDE has grown considerably in the past few decades. While the geriatric population (those 65 years of age or older) accounts for approximately 8% of the current world population, this number is anticipated to double in the next few decades (Dobriansky et al., 2007). The growing aging population will place a huge strain on health care delivery and increase costs, and will put increasing pressure on the global economy and society (Forti et al., 2000; Knickman and Snell, 2002). The age distribution of those with traumatic spinal cord injury (SCI) is characterized by a bimodal distribution, with a peak incidence among young adults, most commonly related to motor vehicle accidents, and a second peak in older individuals, mostly due to unintentional falls (Pickett et al., 2003; Wyndaele and Wyndaele, 2006).

The incidence of traumatic SCI varies globally from 10.4 to 83 per million population per year (Wyndaele and Wyndaele, 2006). Survival among individuals with acute traumatic SCI has improved since the 1970s, but older age at the time of injury is still associated with higher mortality rates in the acute and chronic stages after traumatic SCI (DeVivo et al., 1999; Furlan et al., 2008b). Recent work from our group has shown that neurological recovery is similar in older and younger survivors of SCI, when one accounts for potential confounders including gender, ethnicity, GCS score on admission, co-intervention, drug protocol, cause of SCI, and level and severity of SCI (Furlan et al., 2008b).

The impact of age on functional recovery among survivors of traumatic SCI is still unclear, even though the physiologic changes related to aging are thought to contribute to slower rates of recovery and greater residual disability after acute

¹Department of Genetics and Development, Toronto Western Research Institute, University Health Network, Toronto, Ontario, Canada.

²Lyndhurst Centre, Toronto Rehabilitation Institute, University of Toronto, Toronto, Ontario, Canada.

³Krembil Neuroscience Centre, Spinal Program, Toronto Western Hospital, University Health Network, Toronto, Canada.

⁴Department of Surgery, Division of Neurosurgery and Spinal Program, University of Toronto, Toronto, Ontario, Canada.

traumatic injury (Gershkoff et al., 1993; McKinley et al., 2003). Given this, the present study examines whether age at time of injury affects mortality, motorsensory recovery, and functional recovery in the chronic stage after traumatic SCI using a large, prospectively accrued cohort of spinal cord-injured adults.

Methods

The University Health Network Research Ethics Board and Yale University Human Investigation Committee approved the protocol of this study.

Cohort study

All individuals who were enrolled in the Third National Acute Spinal Cord Injury Study (NASCIS 3) were included in this cohort study (Bracken et al., 1997). The NASCIS 3 is a double-blind, randomized clinical trial that was designed to compare methylprednisolone administered for 24 h, methylprednisolone administered for 48 h, and tirilazad mesylate administered for 48 h in the management of acute traumatic SCI (Bracken et al., 1997).

Inclusion and exclusion criteria for NASCIS-3 are summarized below (Bracken et al., 1997). A patient with acute traumatic SCI had to be randomized within 6 h of injury to receive the study drug within 8 h (Bracken et al., 1997). Patients were considered ineligible if they (1) were pregnant, (2) were an illegal immigrant, (3) were an indicted criminal, (4) had serious co-morbidities or specific health conditions that might affect treatment assessment, (5) weighed more than 109 kg, (6) had a penetrating SCI, (7) had previous spinal injury, (8) had received steroids prior to admission, or (9) were aged under 14 years (Bracken et al., 1997).

Outcome measures

Mortality was assessed at 6 weeks (acute stage), and at 6 and 12 months (chronic stage) following SCI.

Impairment was assessed at 30 days, and at 6 and 12 months after SCI using the NASCIS pain score for response to pain and pressure, as well as the NASCIS motor and sensory scores for neurological recovery (Bracken et al., 1990; Bracken et al., 1992). Pain scores were determined by evaluating responses to deep pain and pressure stimuli in the wrist, thumb, little finger, knee, ankle, and great toe that were scored as 1 (absent), 2 (decreased) and 3 (normal) (Bracken et al., 1997). Change in pain scores was defined as the difference between the baseline and follow-up deep pain and pressure scores. Motor scores included assessment of 14 muscle segments from each body side. Each segment was scored 0 (no contraction), 1 (reduced contraction), 2 (active movement without gravity), 3 (if there was active movement with resistance), 4 (function reduced but active movement against resistance), or 5 (normal function). Unilateral expanded motor scores varied from 0 (no contraction in any muscle) to 70 (normal motor function in 14 muscles). Motor recovery was defined as the difference between each follow-up motor score and the baseline motor score. Sensory function was assessed bilaterally using pinprick and light touch in 29 segments from C2 to S5. Each sensory segment was scored as absent (1), decreased (2), or normal (3). Expanded sensory scores for each measurement varied from 29 (absent at all levels) to 87 (normal at

all levels). Sensory recovery was defined as the difference between the follow-up sensory score and the baseline sensory score. Severity of SCI was divided into complete (absence of motor and sensory function caudal to the level of injury) and incomplete SCI. Severity of SCI was divided into complete (absence of motor and sensory function caudal to the level of injury) and incomplete SCI. Of note, NASCIS motor and sensory scores were reportedly correlated with functional measures based on four indices of activities of daily living (Bracken et al., 1980). The NASCIS motor score was used to validate the American Spinal Injury Association (ASIA) motor score, which subsequently became the gold standard for neurological assessment of spinal cord-injured individuals (El Masry et al., 1996). Our results are compared with studies in which patients were neurologically assessed using the ASIA score.

The acute (6 weeks) to chronic (1 year) stages after SCI are clinically relevant since neurological recovery assessed by the ASIA scores is higher during the first 3 months after injury, and then plateaus in the second half-year following SCI (Waters et al., 1993). Minimal neurological improvement as assessed by the ASIA score was observed between 1 and 5 years after SCI (Kirshblum et al., 2004).

For the assessment of disability, the Functional Independence Measure (FIM) was obtained at 6 weeks, 6 months and 12 months following SCI. In addition to functional status, we estimated functional recovery defined as the difference between FIM scores at 6 weeks and FIM scores at 1 year following SCI. The FIM is an 18-item ordinal scale (range: 0–126) with seven levels for each item (from complete independence to total assist), that includes functional assessment in the areas of self-care, sphincter control, mobility, locomotion, communication, psychosocial adjustment, and cognitive function (Keith et al., 1987). The physical FIM subscore refers to the summed subscores for self-care, sphincter control, and mobility and locomotion items, whereas the cognitive FIM subscore includes the subscores for communication, psychosocial adjustment, and cognitive function. The FIM score has been established as valid and reliable in the functional assessment of spinal cord-injured individuals (Kirshblum et al., 2004).

Data analysis

Mortality at 6 weeks, 6 months, and 1 year after SCI was examined by comparing younger individuals (<65 years of age at the time of SCI) and older patients using Kaplan-Meier curves with log-rank tests. Cox proportional hazards analysis was used to verify potential risk factors for mortality.

Unadjusted and adjusted regression analyses were used to examine the potential correlation between patient age and neurological recovery or change in pain scores at 6 weeks, 6 months, and 1 year following SCI. Furthermore, the potential correlation between neurological recovery and FIM score/subscores was examined using linear regression analysis.

The potential association between patient age and functional status was examined using three statistical methods. First, younger individuals were compared to older patients with regard to FIM score, physical FIM subscore, and cognitive FIM subscore using the two-sided Mann-Whitney U test. Second, an unadjusted linear regression analysis was carried out to test the potential association between patient age and

FIM score/subscores. Finally, the potential correlations between patient age and FIM score/subscores were assessed using multiple linear regression adjusted for sex, ethnic group, GCS score, blood alcohol concentration on admission, NASCIS-3 drug protocol, cause of SCI, and level and severity of SCI.

Given that a ceiling effect for the FIM could affect our data analysis, we also compared both age groups with regard to the proportion of individuals who reached the maximum FIM scores over those ones who had a total FIM score below 125 at each time point using Fisher's exact test. Similarly, the ceiling effect of the FIM scores over time was assessed in each age group at all three time points using Fisher's exact test.

All data analyses were carried out using the SAS program (version 8.02; SAS Institute Inc., Cary, NC).

Results

Of the 499 patients enrolled in the NASCIS-3 trial, 396 spinal cord-injured individuals had complete essential data including FIM scores at 1 year after SCI. There were no significant differences between younger and older individuals

regarding sex, ethnicity, weight, level of SCI, heart rate, arterial blood pressure, blood alcohol concentration, and GCS (Table 1). The two groups did not differ regarding weight, ethnicity, GCS, heart rate, systolic blood pressure, and diastolic blood pressure in the frequency-of-treatment arm of the trial. Older individuals had a significantly greater proportion of males who suffered an incomplete cervical SCI compared with younger individuals. Motor vehicle accidents were the most frequent cause of SCI among younger individuals, whereas falls were the predominant injury mechanism in the elderly.

Mortality

Survival status was obtained for all 499 patients at each time point. There were significant differences between older and younger individuals in mortality at 6 weeks (25.0% versus 2%, respectively; $p < 0.0001$), at 6 months (36.4% versus 2.2%; $p < 0.0001$), and at 1 year after SCI (38.6% versus 3.1%; $p < 0.0001$). Kaplan-Meier curves confirmed that mortality in the elderly group was significantly higher than mortality in the younger group within the first year following SCI (Fig. 1).

TABLE 1. DEMOGRAPHICS AND CLINICAL FEATURES OF THE PATIENTS IN THE COHORT STUDY BY AGE GROUP

Feature	Group		p Value
	Younger individuals	Older individuals	
Number of individuals	455	44	
Age (y)			
Mean	31.9	74	<0.001
Median	30	71.5	
Range (y)	14–64	65–92	
Gender (%)			
Males	82.9	92.7	0.01
Females	17.1	7.3	
Weight ^a (kg)	170 ± 1.4	168.9 ± 4.6	0.97
Ethnic group (%)			
White	82.2	90.9	0.29
Black	12.8	4.55	
Other	5	4.55	
Cause of injury (%)			
Motor vehicle accident	51.5	40.9	<0.001
Fall	21.5	56.8	
Other	27	2.3	
Severity of injury (%)			
Complete	51.9	29.5	0.007
Incomplete	48.1	70.5	
Level of injury (%)			
Cervical level	65.6	89.5	0.002
Thoracolumbar level	34.4	10.5	
Glasgow coma score ^a	14.6 ± 0.05	14.5 ± 0.2	0.6
Heart rate (bpm)	80.8 ± 0.8	76.9 ± 2.4	0.17
Systolic blood pressure (mm Hg)	123.9 ± 1.1	130.3 ± 5	0.13
Diastolic blood pressure (mm Hg)	74.7 ± 0.8	76 ± 2.7	0.79
Blood alcohol concentration ^a (%)	0.05 ± 0.005	0.06 ± 0.03	0.05
Drug intervention ^b (%)			
24-h methylprednisolone	33	36.4	0.67
48-h methylprednisolone	33	36.4	
48-h tirilazad mesylate	34.1	27.3	

^aMean values ± standard error of mean.

^bBy design, patients were randomized to these three treatments.

FIG. 1. Survival of younger versus older individuals with SCI during the first year after SCI using Kaplan-Meier curves analyzed by Cox regression with log-rank tests ($p < 0.0001$).

Using Cox regression analysis, age and severity of SCI were identified as significant risk factors for differences in mortality within the first year following SCI (Table 2).

Motor recovery

Of surviving patients, 83.6% had a 1-year neurological assessment. Age was not significantly associated with motor recovery at 6 weeks after SCI ($R^2 = 0.0003$; $p = 0.69$). However, there was a trend that did not reach significance between age and motor recovery at 6 months after SCI ($R^2 = 0.007$; $p = 0.07$). Older age was significantly but weakly associated with greater motor recovery at 1 year following SCI ($p = 0.05$; Fig. 2A). After controlling for confounders (i.e., sex, ethnic group, GCS score, blood alcohol concentration on admission, NASCIS-3 drug protocol, cause of SCI, and level and severity of SCI), motor recovery in the acute and chronic stages after SCI was not significantly associated with age at the time of injury (Table 3).

Sensory recovery

Among survivors, 83.6% had a sensory assessment at 1 year. Older age was significantly (but weakly) associated with greater sensory recovery at 6 weeks ($R^2 = 0.08$;

$p < 0.0001$), at 6 months ($R^2 = 0.06$; $p < 0.0001$), and 1 year ($p < 0.0001$; Fig. 2B) following SCI. After controlling for major confounders, older age was also significantly associated with better sensory recovery in all stages after SCI (Table 3).

Change in pain scores

Of surviving patients, 85.2% had a deep pain and pressure assessment at 1 year. Age was not significantly associated with change in pain scores at 6 weeks ($R^2 = 0.002$; $p = 0.37$), at 6 months ($R^2 = 0.0002$; $p = 0.78$), and at 1 year following SCI ($p = 0.91$; Fig. 2C). After adjusting for major confounders, there was no significant association between age at the time of trauma and change in pain scores in all stages after SCI (Table 3).

Functional status

Among survivors, 83% had a functional assessment at 1 year. There was a significant but weak association between younger age and greater functional status at 6 weeks after SCI ($R^2 = 0.01$; $p = 0.02$). Age was not significantly correlated with functional status at 6 months ($R^2 = 0.003$; $p = 0.3$), or at 1 year after SCI ($p = 0.46$; Fig. 3A). After controlling for major confounders, there was a significant association between younger age at the time of injury and greater functional status in the acute and chronic stages following SCI (Table 4). However, a ceiling effect exists in all correlations between age and functional status (Fig. 3A). Although the proportion of patients who reached the maximum FIM score in the elderly was numerically lower than those ones in the younger groups, this apparent difference was not statistically significant at all time points (Fig. 3B). While the ceiling effect significantly increased over time among younger individuals ($p < 0.001$), there were no significant differences among the three time points in the proportion of older patients who reached the maximum FIM scores ($p = 0.53$).

Patient age was not significantly associated with physical FIM subscores at 6 weeks ($R^2 = 0.005$; $p = 0.12$), at 6 months ($R^2 = 0.002$; $p = 0.36$), and at 1 year following SCI ($R^2 = 0.004$; $p = 0.21$). In the regression analyses adjusted for major confounders, older age was significantly associated with reduced physical FIM subscores at 6 weeks after SCI, whereas there were no significant associations between age and

TABLE 2. ASSESSMENT OF POTENTIAL RISK FACTORS FOR MORTALITY WITHIN THE FIRST YEAR AFTER TRAUMATIC SPINAL CORD INJURY BASED ON COX REGRESSION ANALYSIS

Potential risk factors	Hazard ratio	95% Confidence interval	p Value
Age (increased risk for each year of life)	1.08	1.05, 1.11	<0.0001
Sex (male or female)	1.64	0.58, 4.6	0.35
Ethnic group (white or other)	0.82	0.24, 2.85	0.76
Cause of SCI (motor vehicle accident or others)	0.78	0.31, 2	0.6
Level of SCI (cervical or thoracolumbar level)	0.94	0.31, 2.82	0.91
Severity of SCI (complete or incomplete)	0.31	0.1, 0.92	0.03
Glasgow coma score on admission	1.33	0.87, 2.02	0.18
Drug intervention (standard ^a or alternative strategy ^b)	2.62	0.93	7.38
Blood alcohol concentration (increase risk for 1%)	0.15	0, 93	0.56

^a24-hour methylprednisolone.

^b48-hour methylprednisolone or 48-hour tirilazad mesylate.

FIG. 2. Results of unadjusted linear regression analyses comparing patient age at time of injury with motor recovery (A), sensory recovery (B), and change in pain score (C) at 1 year after traumatic SCI.

TABLE 3. ASSESSMENT OF POTENTIAL CORRELATIONS BETWEEN AGE AND MOTOR RECOVERY, SENSORY RECOVERY, OR CHANGE IN PAIN SCORES AT 6 WEEKS, 6 MONTHS, AND 1 YEAR AFTER TRAUMATIC SCI BASED ON REGRESSION ANALYSES ADJUSTED FOR POTENTIAL CONFOUNDERS^a

Parameters by time point	At 6 weeks after SCI	At 6 months after SCI	At 1 year after SCI
<i>Motor recovery</i>			
Model	R ² = 0.24 (<i>p</i> < 0.0001)	R ² = 0.26 (<i>p</i> < 0.0001)	R ² = 0.25 (<i>p</i> < 0.0001)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	1.51 (<i>p</i> = 0.22)	0.56 (<i>p</i> = 0.45)	1.09 (<i>p</i> = 0.3)
Sex (male = 1; female = 2)	1.34 (<i>p</i> = 0.07)	0.93 (<i>p</i> = 0.34)	0.26 (<i>p</i> = 0.61)
Ethnic group (black = 1; white = 3; others = 2)	0.93 (<i>p</i> = 0.4)	0.49 (<i>p</i> = 0.61)	0.33 (<i>p</i> = 0.71)
Blood alcohol concentration (per 1% increase)	2.54 (<i>p</i> = 0.11)	0.03 (<i>p</i> = 0.87)	0.00 (<i>p</i> = 0.97)
Level of SCI (cervical = 1; thoracolumbar = 2)	8.45 (<i>p</i> = 0.004)	19.44 (<i>p</i> < 0.0001)	23.25 (<i>p</i> < 0.0001)
Severity of SCI (complete = 1; incomplete = 2)	77.82 (<i>p</i> < 0.0001)	67.85 (<i>p</i> < 0.0001)	61.55 (<i>p</i> < 0.0001)
Cause of SCI (motor vehicle accident = 1; fall = 2; other = 3)	0.06 (<i>p</i> = 0.94)	0.08 (<i>p</i> = 0.92)	0.14 (<i>p</i> = 0.87)
Glasgow coma score (per 1 unit increase)	0.69 (<i>p</i> = 0.41)	0.52 (<i>p</i> = 0.47)	0.6 (<i>p</i> = 0.44)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	1.58 (<i>p</i> = 0.21)	2.63 (<i>p</i> = 0.07)	1.69 (<i>p</i> = 0.19)
<i>Sensory recovery</i>			
Model	R ² = 0.23 (<i>p</i> < 0.0001)	R ² = 0.24 (<i>p</i> < 0.0001)	R ² = 0.24 (<i>p</i> < 0.0001)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	30.28 (<i>p</i> < 0.0001)	27.97 (<i>p</i> < 0.0001)	18.37 (<i>p</i> < 0.0001)
Sex (male = 1; female = 2)	0.4 (<i>p</i> = 0.53)	0.32 (<i>p</i> = 0.57)	0.36 (<i>p</i> = 0.55)
Ethnic group (black = 1; white = 3; others = 2)	5.03 (<i>p</i> = 0.007)	7.51 (<i>p</i> = 0.0006)	6.83 (<i>p</i> = 0.001)
Blood alcohol concentration (per 1% increase)	2.36 (<i>p</i> = 0.12)	0.02 (<i>p</i> = 0.89)	0.00 (<i>p</i> = 0.99)
Level of SCI (cervical = 1; thoracolumbar = 2)	23.52 (<i>p</i> < 0.0001)	32.75 (<i>p</i> < 0.0001)	41.38 (<i>p</i> < 0.0001)
Severity of SCI (complete = 1; incomplete = 2)	4.19 (<i>p</i> = 0.04)	0.06 (<i>p</i> = 81)	0.00 (<i>p</i> = 95)
Cause of SCI (motor vehicle accident = 1; fall = 2; others = 3)	3.01 (<i>p</i> = 0.05)	1.24 (<i>p</i> = 0.29)	1.07 (<i>p</i> = 0.34)
Glasgow coma score (per 1 unit increase)	1.72 (<i>p</i> = 0.19)	2.71 (<i>p</i> = 0.1)	4.26 (<i>p</i> = 0.04)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	2.37 (<i>p</i> = 0.09)	2.3 (<i>p</i> = 0.1)	0.45 (<i>p</i> = 0.64)
<i>Change in pain scores</i>			
Model	R ² = 0.08 (<i>p</i> = 0.002)	R ² = 0.12 (<i>p</i> < 0.0001)	R ² = 0.15 (<i>p</i> < 0.0001)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	0.09 (<i>p</i> = 0.76)	1.24 (<i>p</i> = 28)	1.05 (<i>p</i> = 0.31)
Sex (male = 1; female = 2)	0.35 (<i>p</i> = 0.55)	0.61 (<i>p</i> = 0.43)	0.25 (<i>p</i> = 0.62)
Ethnic group (black = 1; white = 3; others = 2)	0.85 (<i>p</i> = 0.43)	0.91 (<i>p</i> = 0.4)	1.41 (<i>p</i> = 0.24)
Blood alcohol concentration (per 1% increase)	1.25 (<i>p</i> = 0.26)	0.15 (<i>p</i> = 0.7)	0.05 (<i>p</i> = 0.82)
Level of SCI (cervical = 1; thoracolumbar = 2)	13.21 (<i>p</i> = 0.0003)	22.43 (<i>p</i> < 0.0001)	32.85 (<i>p</i> < 0.0001)
Severity of SCI (complete = 1; incomplete = 2)	1.44 (<i>p</i> = 0.23)	0.18 (<i>p</i> = 0.67)	0.66 (<i>p</i> = 0.42)
Cause of SCI (motor vehicle accident = 1; fall = 2; others = 3)	0.7 (<i>p</i> = 0.49)	0.22 (<i>p</i> = 0.8)	0.07 (<i>p</i> = 0.93)
Glasgow coma score (per 1 unit increase)	2.8 (<i>p</i> = 0.09)	5.52 (<i>p</i> = 0.02)	7.13 (<i>p</i> = 0.008)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	1.15 (<i>p</i> = 0.32)	1.61 (<i>p</i> = 0.2)	0.92 (<i>p</i> = 0.4)

^aSex, ethnic group, blood alcohol concentration, cause of injury, level of injury, GCS score, and drug intervention

24-MP, 24-h administration of methylprednisolone; 48-MP, 48-h administration of methylprednisolone; 48-MT, 48-h administration of tirilazad mesylate.

physical FIM subscores at the chronic stage following SCI (Table 4).

While age was significantly (but weakly) associated with cognitive FIM subscore at 6 weeks after SCI ($R^2 = 0.01$; $p = 0.01$), there were no significant correlations between patient age and cognitive FIM subscore at 6 months ($R^2 = 0.006$; $p = 0.1$) or 1 year following SCI ($R^2 = 0.0004$; $p = 0.67$). After controlling for major confounders, age was significantly associated with cognitive FIM subscores at 6 weeks after SCI, but there were no significant correlations between age and cognitive FIM subscores at the chronic stage (Table 4).

Moreover, age was not significantly associated with functional recovery as assessed by the difference between FIM scores at 6 weeks and 1 year after SCI in the unadjusted regression analysis ($R^2 = 0.001$; $p = 0.43$), and after adjusting for

potential confounders ($R^2 = 0.05$; $p = 0.47$). Functional recovery among older people did not significantly differ from functional recovery in the younger group after SCI (18.78 ± 4.28 versus 18.27 ± 0.93 , respectively; $p = 0.77$).

Discussion

This study examined the key question of whether patient age at time of injury influences mortality, impairment, and disability after traumatic SCI, using a large prospectively accrued database. Our results indicated that mortality was significantly higher among older people than in younger people at all stages after SCI. Unlike some of our unadjusted models, the regression analyses controlled for major potential confounders showed no significant correlations

FIG. 3. (A) Results of unadjusted linear regression analysis comparing patient age at the time of SCI and functional status as assessed by FIM at 1 year post-injury. (B) Proportions of spinal cord-injured individuals who reached the maximum FIM score at 6 weeks, 6 months, and 1 year following injury among older and younger individuals.

between age and motor recovery or change in pain scores at the acute and chronic stages after SCI. Older age at the time of injury was associated with greater sensory recovery within the first year following SCI in the regression analyses before and after controlling for major potential confounders. However, those potential benefits of older age in reduced impairment did not translate into better functional outcomes within the first year following traumatic SCI. In reality, older age was associated with greater disability as assessed using the FIM at the acute and chronic stages after SCI.

Mortality after traumatic SCI

Our mortality rates in the acute and chronic stages after traumatic SCI varied from 2–3.1% among younger individuals, and from 25–38.6% among older individuals, which are consistent with results reported in previous studies in which “elderly” was defined as 65 years of age or older (Spivak et al., 1994; Irwin et al., 2004; Jackson et al., 2005; Furlan et al., 2008b). In those previous studies, mortality rates varied from 0.5–4.9% among younger patients, and from 9.7–46.9% in

TABLE 4. ASSESSMENT OF POTENTIAL CORRELATIONS BETWEEN AGE AND FUNCTIONAL STATUS AS ASSESSED BY FIM AT 6 WEEKS, 6 MONTHS, AND 1 YEAR AFTER TRAUMATIC SCI BASED ON REGRESSION ANALYSES ADJUSTED FOR POTENTIAL CONFOUNDERS^a

Parameters by time point	At 6 weeks after SCI	At 6 months after SCI	At 1 year after SCI
<i>Total FIM scores</i>			
Model	R ² = 0.48 (<i>p</i> < 0.0001)	R ² = 0.48 (<i>p</i> < 0.0001)	R ² = 0.46 (<i>p</i> < 0.0001)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	20.2 (<i>p</i> < 0.0001)	9.88 (<i>p</i> = 0.002)	6.83 (<i>p</i> = 0.009)
Sex (male = 1; female = 2)	2.07 (<i>p</i> = 0.15)	0.73 (<i>p</i> = 0.39)	0.31 (<i>p</i> = 0.56)
Ethnic group (black = 1; white = 3; others = 2)	0.43 (<i>p</i> = 0.65)	2.95 (<i>p</i> = 0.05)	0.83 (<i>p</i> = 0.44)
Blood alcohol concentration (per 1% increase)	1.73 (<i>p</i> = 0.19)	0.19 (<i>p</i> = 0.66)	0.04 (<i>p</i> = 0.85)
Level of SCI (cervical = 1; thoracolumbar = 2)	71.02 (<i>p</i> < 0.0001)	7.88 (<i>p</i> < 0.0001)	72.71 (<i>p</i> < 0.0001)
Severity of SCI (complete = 1; incomplete = 2)	191.23 (<i>p</i> < 0.0001)	197.82 (<i>p</i> < 0.0001)	205.4 (<i>p</i> < 0.0001)
Cause of SCI (motor vehicle accident = 1; fall = 2; others = 3)	0.38 (<i>p</i> = 0.68)	1.4 (<i>p</i> = 0.25)	1.84 (<i>p</i> = 0.16)
Glasgow coma score (per 1 unit increase)	11.39 (<i>p</i> = 0.0008)	6.74 (<i>p</i> = 0.01)	6.03 (<i>p</i> = 0.01)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	2.22 (<i>p</i> = 0.11)	1.67 (<i>p</i> = 0.19)	0.43 (<i>p</i> = 0.65)
<i>Physical FIM subscores</i>			
Model	R ² = 0.48 (<i>p</i> < 0.0001)	R ² = 0.03 (<i>p</i> = 0.55)	R ² = 0.06 (<i>p</i> = 0.04)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	8.52 (<i>p</i> = 0.004)	0.11 (<i>p</i> = 0.74)	0.84 (<i>p</i> = 0.36)
Sex (male = 1; female = 2)	0.71 (<i>p</i> = 0.4)	0.11 (<i>p</i> = 0.74)	0.36 (<i>p</i> = 0.55)
Ethnic group (black = 1; white = 3; others = 2)	2.34 (<i>p</i> = 0.1)	0.46 (<i>p</i> = 0.63)	0.11 (<i>p</i> = 0.89)
Blood alcohol concentration (per 1% increase)	0.02 (<i>p</i> = 0.88)	3.19 (<i>p</i> = 0.07)	15.14 (<i>p</i> = 0.0001)
Level of SCI (cervical = 1; thoracolumbar = 2)	77.95 (<i>p</i> < 0.0001)	1.26 (<i>p</i> = 0.26)	0.49 (<i>p</i> = 0.49)
Severity of SCI (complete = 1; incomplete = 2)	207.11 (<i>p</i> < 0.0001)	4.29 (<i>p</i> = 0.4)	1.31 (<i>p</i> = 0.25)
Cause of SCI (motor vehicle accident = 1; fall = 2; others = 3)	1.33 (<i>p</i> = 0.27)	0.29 (<i>p</i> = 0.75)	0.78 (<i>p</i> = 0.46)
Glasgow coma score (per 1 unit increase)	5.63 (<i>p</i> = 0.02)	0.7 (<i>p</i> = 0.4)	1.03 (<i>p</i> = 0.31)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	1.83 (<i>p</i> = 0.16)	0.17 (<i>p</i> = 0.84)	0.6 (<i>p</i> = 0.55)
<i>Cognitive FIM subscores</i>			
Model	R ² = 0.11 (<i>p</i> < 0.0001)	R ² = 0.03 (<i>p</i> = 0.58)	R ² = 0.01 (<i>p</i> = 0.94)
Variables	F value (<i>p</i> value)	F value (<i>p</i> value)	F value (<i>p</i> value)
Patient age (per 1 year increase)	5.67 (<i>p</i> = 0.02)	2.01 (<i>p</i> = 0.16)	0.11 (<i>p</i> = 0.74)
Sex (male = 1; female = 2)	0.14 (<i>p</i> = 0.71)	0 (<i>p</i> = 0.99)	1.79 (<i>p</i> = 0.18)
Ethnic group (black = 1; white = 3; others = 2)	5.24 (<i>p</i> = 0.006)	0.83 (<i>p</i> = 0.44)	0.17 (<i>p</i> = 0.84)
Blood alcohol concentration (per 1% increase)	66.78 (<i>p</i> = 0.01)	0.45 (<i>p</i> = 0.5)	0.53 (<i>p</i> = 0.47)
Level of SCI (cervical = 1; thoracolumbar = 2)	0.71 (<i>p</i> = 0.4)	0.4 (<i>p</i> = 0.53)	0.49 (<i>p</i> = 0.48)
Severity of SCI (complete = 1; incomplete = 2)	4.73 (<i>p</i> = 0.03)	1.33 (<i>p</i> = 0.25)	1.34 (0.25)
Cause of SCI (motor vehicle accident = 1; fall = 2; others = 3)	0.59 (<i>p</i> = 0.56)	0.16 (<i>p</i> = 0.85)	0.01 (<i>p</i> = 0.99)
Glasgow coma score (per 1 unit increase)	7.11 (<i>p</i> = 0.008)	0.11 (<i>p</i> = 0.74)	0.5 (<i>p</i> = 0.48)
Drug intervention (48-TM = 1; 24-MP = 2; 48-MP = 3)	0.17 (<i>p</i> = 0.84)	1.74 (<i>p</i> = 0.18)	0.01 (<i>p</i> = 0.99)

^aSex, ethnic group, blood alcohol concentration, cause of injury, level of injury, Glasgow coma score, and drug intervention
24-MP, 24-hour administration of methylprednisolone; 48-MP, 48-h administration of methylprednisolone; 48-MT, 48-h administration of tirilazad mesylate.

older patients (Spivak et al., 1994; Irwin et al., 2004; Jackson et al., 2005; Furlan et al., 2008b). Most deaths occurred within 6 weeks following traumatic SCI in our series, which was essentially similar to the findings of O'Connor (O'Connor, 2005).

Our data indicate that the mortality rates among older people are substantially higher than those of younger individuals. Jackson and associates also reported a significant difference in the mortality rates between older and younger individuals at 1 year after cervical spine injuries (Jackson et al., 2005). In-hospital and 60-day mortality rates were significantly greater among older people than in younger people following spine trauma in a population-based study that included 10,002 spinal cord-injured individuals (Irwin et al.,

2004). In a prior study based on the NASCIS-2 data, older people had substantially greater mortality rates at 30 days, 6 months, and 1 year after SCI compared to younger people (Furlan et al., 2008b).

We estimated a hazard ratio of 1.08 for each 1-year increase in patient age at the time of injury for death within the first year following SCI. This was similar to the results of a previous study based on the NASCIS-2 data, which found a 1.06 hazard ratio for each 1-year increase in age for death at 1 year after SCI (Lidal et al., 2007). Strauss and colleagues reported that the odds of dying in a given person-year increase by 7% per year based on data from the National Spinal Cord Injury Statistical Center (NSCISC) database of 38,870 people who survived the first 24 h after traumatic SCI (Strauss et al., 2006).

In a retrospective study of 387 Norwegian patients with SCI, the relative risk of dying increased by 0.08 for each year of advancing age at the time of injury (Lidal et al., 2007).

The reasons for this higher mortality rate in the elderly after SCI are incompletely understood. A previous study indicated that pre-existing medical co-morbidities partially account for the increased mortality in the geriatric population after traumatic SCI (Furlan et al., 2008a). Although "ageism" has been reported among scientists, clinicians, and allied health professionals who care for patients with neurotrauma, further investigation is needed to determine the potential influence of ageism on mortality and other outcomes after traumatic SCI (Hesse et al., 1984; Furlan et al., 2009; Furlan and Fehlings, 2009). In addition to those two factors, it is reasonable to assume that older people have a more limited life span than younger individuals.

Impairment after traumatic SCI

In our study, older age was associated with greater motor recovery at 1 year after SCI in an unadjusted regression analysis. Importantly, however, with control for key confounding variables, there was no significant correlation between age and motor recovery. Interestingly, older age appeared to be consistently but weakly associated with greater sensory recovery in the acute and chronic stages after traumatic SCI.

Using a large cohort of spinal cord-injured individuals from the NSCISC database, Cifu and Seel and colleagues performed a series of studies to examine whether age potentially affects neurological outcomes after traumatic SCI (Cifu et al., 1999a; Cifu et al., 1999c; Cifu et al., 1999b; Seel et al., 2001). In their unmatched study of tetraplegics, neurological recovery as assessed by ASIA motor score was greater in patients aged 45–59 years than in individuals older than 70 years at the time of SCI (Cifu et al., 1999a). Nonetheless, all age groups were statistically comparable with regard to ASIA motor efficiency scores (defined as the ratio between neurological recovery and length of stay in the rehabilitation facility) (Cifu et al., 1999a). Their age groups did not differ significantly with regard to the ASIA motor recovery between admission and discharge from acute medical care and from inpatient rehabilitation, whereas there were significant differences for the ASIA motor recovery between admission on acute medical care and discharge from inpatient rehabilitation (Cifu et al., 1999a). In another unmatched study of paraplegics that was controlled for level and completeness of SCI using factorial ANOVA, age groups did not differ significantly with regard to ASIA motor efficiency scores and neurological recovery as assessed by ASIA motor score (Cifu et al., 1999c). In a study of a cohort of tetraplegics in whom age groups were matched for level and severity of SCI, younger people had greater neurological recovery and lower ASIA motor efficiency scores than older people (Cifu et al., 1999b). However, potential selection bias existed in that study because all patients who died during hospitalization were excluded from the results (Cifu et al., 1999b). In another study of paraplegics in whom age groups were matched for level and severity of SCI, there were no significant differences among age groups with regard to ASIA motor scores on admission to the acute care unit and at discharge from the inpatient rehabilitation facility (Seel et al., 2001).

More recently, another study examined patient age as a potential determinant of neurological recovery in a series of 485 patients who were enrolled in the NASCIS-2 trial (Furlan et al., 2008b). Among survivors, age was not significantly associated with motor and sensory outcomes at 6 weeks, 6 months, and 1 year after SCI in univariate and multivariate analyses with or without adjustments for potential confounders (Furlan et al., 2008b). In addition, a neuroanatomical analysis of post-mortem spinal cord tissue was carried out, revealing no significant age-related differences regarding extent of myelin degeneration or number of intact axons within sensory, motor, and autonomic spinal cord tracts following SCI (Furlan et al., 2008b).

In the present study, changes in pain scores in the acute and chronic stages after SCI were not significantly associated with age in all regression analyses. In a cross-sectional longitudinal study, Hanley and associates reported that age at the time of injury was not significantly correlated with pain intensity (as assessed by a numerical rating scale from 0–10) or pain interference (as assessed by the Brief Pain Inventory Interference Scale) among 40 individuals with chronic SCI (mean time since injury of 17.9 years) (Hanley et al., 2008). Similarly, Ullrich and colleagues found no significant association between age at the time of injury and pain intensity or interference in a cross-sectional observational study that included 392 individuals with chronic SCI (mean time since injury of 11 years) (Ullrich et al., 2008). However, Werhagen and co-workers reported a significant correlation between older age and the occurrence of neuropathic pain as defined using the International Association for the Study of Pain criteria in a cohort of 402 patients with SCI (mean age since injury of 6 years) (Werhagen et al., 2004). Aito and associates also reported a higher frequency of neuropathic pain among older people after traumatic central cord syndrome (Aito et al., 2007).

Disability after traumatic SCI

Our results indicate that older age was significantly correlated with reduced functional status within the first year after SCI, using either unadjusted regression analyses or after controlling for potential confounders. However, there was no significant correlation between age and functional recovery from 6 weeks to 1 year after SCI.

Cifu and Seel and their colleagues also studied the potential influence of age on functional outcomes following traumatic SCI using the NSCISC database (Cifu et al., 1999a; Cifu et al., 1999c; Cifu et al., 1999b; Seel et al., 2001). In the unmatched study of tetraplegics, age groups were statistically comparable regarding FIM change scores from admission to discharge in the rehabilitation setting, as were FIM efficiency scores (calculated by dividing change scores by the respective length of stay) (Cifu et al., 1999a). In the unmatched study of paraplegics in which data analyses were controlled for level and completeness of SCI using factorial ANOVA, older people showed significantly lower FIM change scores and lower FIM efficiency scores than younger individuals (Cifu et al., 1999c). In the study of individuals with tetraplegia, after matching age groups for level and severity of SCI, older people had significantly reduced FIM change scores and decreased FIM efficiency scores than younger individuals (Cifu et al., 1999b). In the study of paraplegics, when age groups were matched

for level and severity of SCI, Seel and colleagues reported reduced FIM change scores and decreased FIM efficiency scores among older people compared to those of younger individuals (Seel et al., 2001).

Furthermore, Putzke and associates retrospectively studied 6132 individuals with traumatic SCI who were enrolled in the NSCISC database (Putzke et al., 2003). Their unadjusted ANOVA indicated a significant linear decline of FIM scores in the chronic stage after SCI that correlated with patient age (Putzke et al., 2003). In the multivariate regression analysis adjusted for demographics, educational level, and injury characteristics, older age was significantly associated with lower FIM scores in the chronic stage of SCI, and the incremental adjusted R^2 associated with age was 1% (Putzke et al., 2003). Based on a cohort of 82 patients with traumatic central cord syndrome, Aito and co-workers also reported that older age was significantly associated with reduced FIM scores on discharge from the rehabilitation setting and at follow-up assessment at 18 months after discharge (mean time of 34 months) (Aito et al., 2007).

Study limitations

Our data have relatively high quality with only a few missing data points, since this cohort of patients with SCI was prospectively accrued for a randomized clinical trial. Nonetheless, the lack of detailed data on pre-existing medical co-morbidities precluded further analyses to enable better understanding of the higher mortality rates among older individuals after SCI. Given that "ageism" has been reported among scientists, clinicians, and allied health professionals who care for patients with neurotrauma, we cannot exclude the potential effects of ageism on the outcomes in acute SCI care and rehabilitation care (Hesse et al., 1984; Furlan et al., 2009; Furlan and Fehlings, 2009).

In prior studies researchers reported limitations of the use of FIM for functional assessment in the SCI population (Hall et al., 1999; Lawton et al., 2006). Similarly to those studies, a significant ceiling effect was found for FIM in the assessment of spinal cord-injured individuals, that increased from earlier to later stages (Hall et al., 1999; Lawton et al., 2006). Our results also suggest that this ceiling effect appears to be more common among younger people than older people at all three time points after SCI, even though those differences did not reach significance. The greater proportion of paraplegics among younger individuals than in older people is one potential explanation for the apparent differences seen between the two patient groups with regard to the ceiling effects of FIM scores.

In conclusion, the review of previous investigations of the potential effects of age in neurological and functional outcomes following SCI suggests that heterogeneity in results may depend on methodology. Therefore matching techniques or adjusted data analyses should be applied to control potential major confounders, including demographics, injury characteristics, and treatment protocols. Moreover, the geriatric group has a substantially increased mortality rate during the first year following traumatic SCI compared to younger individuals. Among survivors, though there is potential for older patients with SCI to neurologically improve within the first year post-injury, this does not appear to translate into functional recovery as in younger individuals. Given this fact,

rehabilitation protocols that are more focused on functional recovery may reduce disability among older people with acute traumatic SCI.

Acknowledgments

We greatly thank Dr. Michael B. Bracken for sharing the NASCIS-3 database to carry out this research work. Dr. Fehlings is the Krembil Chair in Neural Repair and Regeneration.

Author Disclosure Statement

No conflicting financial interests exist.

References

- Aito, S., D'Andrea, M., Werhagen, L., Farsetti, L., Cappelli, S., Bandini, B., and Di Donna, V. (2007). Neurological and functional outcome in traumatic central cord syndrome. *Spinal Cord* 45, 292–297.
- Bracken, M.B., Hildreth, N., Freeman, D.H., Jr., and Webb, S.B. (1980). Relationship between neurological and functional status after acute spinal cord injury: an epidemiological study. *J. Chronic Dis.* 33, 115–125.
- Bracken, M.B., Shepard, M.J., Collins, W.F., Holford, T.R., Young, W., Baskin, D.S., Eisenberg, H.M., Flamm, E., Leo-Summers, L., Maroon, J., et al. (1990). A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury. Results of the Second National Acute Spinal Cord Injury Study. *N. Engl. J. Med.* 322, 1405–1411.
- Bracken, M.B., Shepard, M.J., Collins, W.F., Jr., Holford, T.R., Baskin, D.S., Eisenberg, H.M., Flamm, E., Leo-Summers, L., Maroon, J.C., Marshall, L.F., et al. (1992). Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data. Results of the second National Acute Spinal Cord Injury Study. *J. Neurosurg.* 76, 23–31.
- Bracken, M.B., Shepard, M.J., Holford, T.R., Leo-Summers, L., Aldrich, E.F., Fazl, M., Fehlings, M., Herr, D.L., Hitchon, P.W., Marshall, L.F., Nockels, R.P., Pascale, V., Perot, P.L., Jr., Piepmeyer, J., Sonntag, V.K., Wagner, F., Wilberger, J.E., Winn, H.R., and Young, W. (1997). Administration of methylprednisolone for 24 or 48 hours or tirilazad mesylate for 48 hours in the treatment of acute spinal cord injury. Results of the Third National Acute Spinal Cord Injury Randomized Controlled Trial. National Acute Spinal Cord Injury Study. *J.A.M.A.* 277, 1597–1604.
- Cifu, D.X., Huang, M.E., Kolakowsky-Hayner, S.A., and Seel, R.T. (1999c). Age, outcome, and rehabilitation costs after paraplegia caused by traumatic injury of the thoracic spinal cord, conus medullaris, and cauda equina. *J. Neurotrauma* 16, 805–815.
- Cifu, D., Seel, R., Kreutzer, J., Martwitz, J., McKinley, W., and Wisor, D. (1999a). Age, outcome, and rehabilitation costs after tetraplegia spinal cord injury. *NeuroRehabilitation* 12, 177–185.
- Cifu, D.X., Seel, R.T., Kreutzer, J.S., and McKinley, W.O. (1999b). A multicenter investigation of age-related differences in lengths of stay, hospitalization charges, and outcomes for a matched tetraplegia sample. *Arch. Phys. Med. Rehabil.* 80, 733–740.
- DeVivo, M.J., Krause, J.S., and Lammertse, D.P. (1999). Recent trends in mortality and causes of death among persons with spinal cord injury. *Arch. Phys. Med. Rehabil.* 80, 1411–1419.

- Dobriansky, P.J., Suzman, R.M., and Hodes, R.J. (2007). Why population aging matters: A global perspective. U.S. Department of State, U.S. Department of Health and Human Services, National Institute on Aging, and National Institutes of Health: Washington, DC, pps. 1–32.
- El Masry, W.S., Tsubo, M., Katoh, S., El Miligui, Y.H., and Khan, A. (1996). Validation of the American Spinal Injury Association (ASIA) motor score and the National Acute Spinal Cord Injury Study (NASCIS) motor score. *Spine* 21, 614–619.
- Forti, E.M., Johnson, J.A., and Graber, D.R. (2000). Aging in America: challenges and strategies for health care delivery. *J. Health Hum. Serv. Adm.* 23, 203–213.
- Furlan, J.C., and Fehlings, M. (2009). Attitudes toward the elderly with CNS trauma: A cross-sectional study of neuroscientists, clinicians and allied-health professionals. *J. Neurotrauma* 26, 209–225.
- Furlan, J.C., Bracken, M.B., and Fehlings, M.G. (2008b). Is age a key determinant of mortality and neurological outcome after acute traumatic spinal cord injury? *Neurobiol. Aging*, June 10 [Epub ahead of print].
- Furlan, J.C., Craven, B.C., Ritchie, R., Couskos, L., and Fehlings, M. (2009) Attitudes towards the older patients with spinal cord injury among registered nurses: A cross-sectional observational study. *Spinal Cord*, April 14 [Epub ahead of print].
- Furlan, J.C., Kattail, D., and Fehlings, M. (2008a) The impact of comorbidities on age-related differences in mortality after acute traumatic spinal cord injury. *J. Neurotrauma* 26, 1361–1367.
- Gershkoff, A.M., Cifu, D.X., and Means, K.M. (1993). Geriatric rehabilitation. 1. Social, attitudinal, and economic factors. *Arch. Phys. Med. Rehabil.* 74, S402–S405.
- Hall, K.M., Cohen, M.E., Wright, J., Call, M., and Werner, P. (1999). Characteristics of the Functional Independence Measure in traumatic spinal cord injury. *Arch. Phys. Med. Rehabil.* 80, 1471–1476.
- Hanley, M.A., Raichle, K., Jensen, M., and Cardenas, D.D. (2008). Pain catastrophizing and beliefs predict changes in pain interference and psychological functioning in persons with spinal cord injury. *J. Pain* 9, 863–871.
- Hesse, K.A., Campion, E.W., and Karamouz, N. (1984). Attitudinal stumbling blocks to geriatric rehabilitation. *J. Am. Geriatr. Soc.* 32, 747–750.
- Irwin, Z.N., Arthur, M., Mullins, R.J., and Hart, R.A. (2004). Variations in injury patterns, treatment, and outcome for spinal fracture and paralysis in adult versus geriatric patients. *Spine* 29, 796–802.
- Jackson, A.P., Haak, M.H., Khan, N., and Meyer, P.R. (2005). Cervical spine injuries in the elderly: acute postoperative mortality. *Spine* 30, 1524–1527.
- Keith, R.A., Granger, C.V., Hamilton, B.B., and Sherwin, F.S. (1987). The functional independence measure: a new tool for rehabilitation. *Adv. Clin. Rehabil.* 1, 6–18.
- Kirshblum, S., Millis, S., McKinley, W., and Tulsky, D. (2004). Late neurologic recovery after traumatic spinal cord injury. *Arch. Phys. Med. Rehabil.* 85, 1811–1817.
- Knickman, J.R., and Snell, E.K. (2002). The 2030 problem: caring for aging baby boomers. *Health Serv. Res.* 37, 849–884.
- Lawton, G., Lundgren-Nilsson, A., Biering-Sorensen, F., Tesio, L., Slade, A., Penta, M., Grimby, G., Ring, H., and Tennant, A. (2006). Cross-cultural validity of FIM in spinal cord injury. *Spinal Cord* 44, 746–752.
- Lidal, I.B., Snekkevik, H., Aamodt, G., Hjeltne, N., Biering-Sorensen, F., and Stanghelle, J.K. (2007). Mortality after spinal cord injury in Norway. *J. Rehabil. Med.* 39, 145–151.
- McKinley, W., Cifu, D., Seel, R., Huang, M., Kreutzer, J., Drake, D., and Meade, M. (2003). Age-related outcomes in persons with spinal cord injury: a summary paper. *NeuroRehabilitation* 18, 83–90.
- O'Connor, P.J. (2005). Survival after spinal cord injury in Australia. *Arch. Phys. Med. Rehabil.* 86, 37–47.
- Pickett, W., Simpson, K., Walker, J., and Brison, R.J. (2003). Traumatic spinal cord injury in Ontario, Canada. *J. Trauma* 55, 1070–1076.
- Putzke, J.D., Barrett, J.J., Richards, J.S., and DeVivo, M.J. (2003). Age and spinal cord injury: an emphasis on outcomes among the elderly. *J. Spinal Cord Med.* 26, 37–44.
- Seel, R.T., Huang, M.E., Cifu, D.X., Kolakowsky-Hayner, S.A., and McKinley, W.O. (2001). Age-related differences in length of stays, hospitalization costs, and outcomes for an injury-matched sample of adults with paraplegia. *J. Spinal Cord Med.* 24, 241–250.
- Spivak, J.M., Weiss, M.A., Cotler, J.M., and Call, M. (1994). Cervical spine injuries in patients 65 and older. *Spine* 19, 2302–2306.
- Strauss, D.J., Devivo, M.J., Paculdo, D.R., and Shavelle, R.M. (2006). Trends in life expectancy after spinal cord injury. *Arch. Phys. Med. Rehabil.* 87, 1079–1085.
- Ullrich, P.M., Jensen, M.P., Loeser, J.D., and Cardenas, D.D. (2008). Pain intensity, pain interference and characteristics of spinal cord injury. *Spinal Cord* 46, 451–455.
- Waters, R.L., Adkins, R.H., Yakura, J.S., and Sie, I. (1993). Motor and sensory recovery following complete tetraplegia. *Arch. Phys. Med. Rehabil.* 74, 242–247.
- Werhagen, L., Budh, C.N., Hultling, C., and Molander, C. (2004). Neuropathic pain after traumatic spinal cord injury—relations to gender, spinal level, completeness, and age at the time of injury. *Spinal Cord* 42, 665–673.
- Wyndaele, M., and Wyndaele, J.J. (2006). Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? *Spinal Cord* 44, 523–529.

Address correspondence to:

Julio C. Furlan, M.D., M.B.A., M.Sc., Ph.D.
 Toronto Western Research Institute
 399 Bathurst Street, McL 12-407
 Toronto, Ontario, Canada M5T 2S8

E-mail: jcfurlan@gmail.com