Neurological and functional recovery after thoracic spinal cord injury

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Objective: To describe neurological and functional outcomes after traumatic paraplegia.

Design: Retrospective analysis of longitudinal database.

Setting: Spinal Cord Injury Model Systems.

Participants: Six hundred sixty-one subjects enrolled in the Spinal Cord Injury Model Systems database, injured between 2000 and 2011, with initial neurological level of injury from T2–12. Two hundred sixty-five subjects had second neurological exams and 400 subjects had Functional Independence Measure (FIM) scores ≥ 6 months after injury.

Outcome Measures: American Spinal Injury Association Impairment Scale (AIS) grade, sensory level (SL), lower extremity motor scores (LEMS), and FIM.

Results: At baseline, 73% of subjects were AIS A, and among them, 15.5% converted to motor incomplete. The mean SL increase for subjects with an AIS A grade was 0.33 ± 0.21 ; 86% remained within two levels of baseline. Subjects with low thoracic paraplegia (T10–12) demonstrated greater LEMS gain than high paraplegia (T2–9), and also had higher 1-year FIM scores, which had not been noted in earlier reports. Better FIM scores were also correlated with better AIS grades, younger age and increase in AIS grade. Ability to walk at 1 year was associated with low thoracic injury, higher initial LEMS, incomplete injury and increase in AIS grade.

Conclusion: Little neurological recovery is seen in persons with complete thoracic SCI, especially with levels above T10. Persons who are older at the time of injury have poorer functional recovery than younger persons. Conversion to a better AIS grade is associated with improvement in self-care and mobility at 1 year.

Keywords: Outcomes, Recovery, Rehabilitation, Spinal cord injuries, Paraplegia

Introduction

Thoracic spinal cord injury (SCI) causes devastating reductions in motor, sensory, and functional abilities. Younger adults are disproportionately affected by SCI, and their injuries are often due to more violent and traumatic etiologies. They may have greater neurologic injury, but they have fewer baseline medical complications and are thought to be more adaptable. Some studies have shown greater improvement compared to their older counterparts when controlled for injury completeness, while others have found no discernible differences.^{1,2}

Many research activities are underway to develop treatments that can be used to enhance recovery after

SCI, and there are a number of clinical trials underway or in planning to evaluate the effectiveness of promising therapies.³ Information on the usual course of recovery after traumatic SCI is critical to planning clinical trials. Recovery after tetraplegia based on data from the SCI model systems (SCIMS) was recently reported.⁴ Neurologic recovery of persons with paraplegia from the SCIMS database was last reported in 1999.⁵ In that report total motor score was used to document motor recovery. Since then, the motor score has been separated into upper extremity (UEMS) and lower extremity motor scores (LEMS) as this gives a more accurate picture of impairment and better predicts functional abilities.⁶

The focus of this study is to examine the neurological and functional recovery of persons with thoracic SCI. A retrospective analysis of the SCIMS database was used to (1) describe neurologic recovery in terms of sensory

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level, American Spinal Injury Association Impairment Scale (AIS) grade, and LEMS among subjects with paraplegia; (2) compare LEMS changes among different AIS grades and sensory level groups; (3) compare Functional Independence Measure (FIM) improvements and (4) ability to walk among different AIS grades, sensory level groups, and age groups.

The Sygen clinical trial, European Multi-center study about Spinal Cord Injury (EMSCI) and SCIMS databases contain longitudinal data on patient outcomes.^{4,7,8} The present study differs from those reports in several important ways. The Sygen data is based on subjects enrolled in a clinical trial who had to meet extensive inclusion criteria. Their recovery may differ from the broader population of persons with acute traumatic SCI. The EMSCI reports have included subjects with an initial neurological examination up to 30 days post injury.^{7,9} We have restricted this report to subjects with an initial examination within 7 days of injury. Finally, we report both neurological and functional outcomes which have not been reported together by the SCIMS since 1995.¹⁰

Methods

We conducted a retrospective analysis of AIS grade, LEMS, sensory level, FIM scores, and walking status of subjects from the SCIMS database. The sample consisted of subjects with traumatic SCI who were injured between 2000 and 2011, at least 15 years old at the time of injury, admitted within 1 day of injury, and given a neurologic examination within 1 week of injury. The sample was limited to subjects with sensory levels from T2–12 on initial examination. Children under 15 were excluded because their neurological exams are less reliable.¹¹ In the SCIMS, demographic data on the patient and injury are collected at the time of enrollment; neurological data such as motor scores, sensory levels, and AIS grade are collected at system admission, rehabilitation admission, rehabilitation discharge, and 1-year post-injury. The motor FIM score is obtained at the latter three time points. The SCIMS database includes data on persons with SCI from multiple institutions. The research protocol was approved by each contributing center's institutional review board and conformed with the Helsinki Declaration of 1975, as revised in 2000.

Data processing

There were 765 subjects who fit the inclusion criteria listed above. Subjects were considered to have paraplegia if at the initial neurological exam, they had a sensory level between T2–12 and had upper extremity

key muscle scores of 4 or 5. Although the current version of the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) requires a motor grade of 5 for all key muscles above the motor level, earlier versions allowed grades 4 or 5.¹² A grade of 4 could be assigned if there was not full effort by the patient but the examiner felt that this was due to pain or other inhibiting factors. These muscles would now be graded 5*, which was not an option at the time. Five additional subjects who had isolated focal upper extremity motor deficits above the T1 level were also included in the analysis. Of the original 765 subjects, we excluded 39 subjects with missing key muscle motor scores, 63 subjects whose UEMS did not fit the criteria for paraplegia, and two subjects who had unidentifiable AIS grades. The final sample consisted of 661 subjects.

Subjects with a complete neurologic exam more than 182 days after injury were included in the one-year neurological analysis, while subjects with a complete FIM score more than 182 days after injury were used in the one-year functional analysis. We used the 6-month cutoff for one-year data because this is the lower limit of the one-year assessment in the SCIMS database (12 months $\pm$ 6 months). In addition, prior studies have found that the majority of neurological recovery occurs in the first 6 months, so that the neurological results should be minimally impacted.¹³ Functional abilities have a longer recovery period, so it is possible that the FIM and ambulation results underestimate final recovery.¹⁴ We checked the AIS grades using a computerized classification algorithm developed by one of the authors. Forty (6%) of the AIS grades recorded at admission and 22 (3%) of AIS grades recorded at one year were reclassified. The revised classification was confirmed by two of the authors (B.L, R.M.). Six subjects at one year had unknown AIS grades and were removed from the neurologic recovery analyses. There were 265 (40%) subjects who had neurologic data at one year and 400 (61%) who had FIM data at one year (Fig. 1).

Data analysis

We compared the subjects who had 1-year data to subjects missing 1-year data for differences in age, sex, race and initial AIS grade. We used the more rostral sensory level to stratify the AIS grade A subjects into upper (T2–5), middle (T6–9) and low (T10–12) groups. Where there were no significant differences between the upper and middle thoracic groups we combined these into a high thoracic group (T2–9) to compare to the low thoracic group.

Figure 1 Flowchart of subject selection based on inclusion and exclusion criteria.

We determined the frequency and direction of changes in single sensory level and the effect of initial AIS grade and sensory level group on change in sensory level. We calculated the percentage of AIS grade changes from admission to one year. We used a χ^2 analysis to determine if initial sensory level group was related to AIS grade conversions. Similarly, we calculated changes in LEMS from admission to one year using based on initial AIS grade and sensory level group, using a Tukey's test to detect differences between groups.

Differences in FIM scores among different initial AIS grades, sensory level groups, and age groups were compared using Tukey's test. For age-related differences, we divided the subjects into six groups with ages 15–20, 21–30, 31–40, 41–50, 51–60, and >60. We created a linear mixed effects model using initial AIS grade, sensory level group, and age group to predict 1-year FIM scores. We used a *t*-test to compare the FIM scores of subjects who had an increase in AIS grade compared to those who did not, and added 'increase in AIS grade' as a dichotomous variable to the prior linear mixed effects model to determine if there was any additional impact of gain in AIS grade on FIM scores. We also looked at changes in FIM score for subjects with AIS grades A–C combined in order to compare with prior reports^{10,14} and because functionally persons with these grades have similar FIM scores but differ from those who are AIS grade D.¹⁰

Subjects were considered to be walking if they had a FIM walking score of five or higher and FIM mode of

walking, which represented the ability to walk 50 m without physical assistance. A χ^2 test was used to compare the probability of walking for a subject with AIS grade A with all other AIS grades. We used a χ^2 analysis to compare the probability of walking between subjects with complete vs. incomplete injuries, subjects with zero vs. nonzero LEMS, subjects who were younger or older than 50 years, and among subjects with an AIS A grade of different sensory level groups. We used a logistic mixed effects model to create a model of probability of walking based on initial AIS grade, age group, and sensory level group.

Results

Demographics

The 661 subjects were recruited from 18 SCIMS Centers, with centers contributing between 1 and 92 subjects. Subject demographics are summarized in Table 1. The mean age at injury was 34.8 ± 14.6 years with a range from 15–81 years. The majority of subjects had complete injuries (73% AIS grade A); 12% were grade B, 9% grade C, and 6% grade D at initial examination. The most common levels of injury at admission were T12 (17.2%), T10 (15.1%), T11 (12.2%) and T4 (11.6%). We found no significant differences in sex, race, or initial AIS grade between those with and without one-year neurological data (1-y NE) or FIM data (1-y FIM). The mean age at injury was 33 ± 13 years among 1-y NE subjects and 34 ± 14 years for 1-y FIM subjects, and the median was 30 years for

Table 1 Demographics of subjects with and without 1-year neurological exam and Functional Independence Measure scores

Variable	Total <i>n</i>	1-y NE Present		1-y NE Missing		P	1-y FIM Present		1-y FIM Missing		P
		<i>n</i>	%	<i>n</i>	%		<i>n</i>	%	<i>n</i>	%	
Sex											
Men	519	208	78.5	311	78.5	0.99	314	78.5	205	78.5	0.99
Women	142	57	21.5	85	21.5		86	21.5	56	21.5	
Race/ethnicity											
White	425	170	60.3	255	60.3	0.69	257	61.2	168	58.9	0.84
Black	202	82	29.1	120	28.4		122	29.0	80	28.1	
Hispanic	63	23	8.2	40	9.5		31	7.4	32	11.2	
Other	15	7	2.5	8	1.9		10	2.4	5	1.8	
Age											
15–20	107	43	16.2	64	16.2	0.32	74	18.5	33	12.6	0.4
21–30	210	91	34.3	119	30.1		127	31.8	83	31.8	
31–40	144	60	22.6	84	21.2		85	21.3	59	22.6	
41–50	93	39	14.7	54	13.6		55	13.8	38	14.6	
51–60	61	18	6.8	43	10.9		35	8.8	26	10.0	
>60	46	14	5.3	32	8.1		24	6.0	22	8.4	
Initial AIS grade											
A	482	194	73.2	288	72.7	0.75	296	74.0	186	71.3	0.09
B	78	34	12.8	44	11.1		51	12.8	27	10.3	
C	61	21	7.9	40	10.1		36	9.0	25	9.6	
D	40	16	6.0	24	6.1		17	4.3	23	8.8	

1-y NE, one-year neurological exam; 1-y FIM, one-year Functional Independence Measure.

both groups. For both groups, the mean age was 2.4 years younger than the excluded subjects ($P < 0.05$).

The median time between initial injury and the discharge was 66 ± 45 days for the neurologic group and 66 ± 43 for the FIM group. The medians were 53 and 55 respectively. The most common causes of injury were vehicular accidents (44% for 1-y NE and 40% for 1-y FIM), violence (25% for 1-y NE and 26% for 1-y FIM), and falls (26% for 1-y NE and 25% for 1-y FIM). For 1-y NE subjects, the mean time between injury and the one-year exam was 363 ± 102 days, while the mean for 1-y FIM subjects was 430 ± 100 days. The medians were 365 and 413 days respectively.

Sensory level changes

For the 1-y NE group, 90.2% of subjects had symmetric levels and the most common levels of injury at admission were T12 (20.0%), T10 (16.2%), T11 (14.7%) and T4 (10.9%). The average change in level for AIS A subjects was 0.33 ± 2.86 levels; the change for subjects with incomplete injuries was 1.78 ± 4.59 levels ($P < 0.05$).

The absolute change in sensory levels, ignoring direction of change, was 1.5 ± 2.5 levels for complete and 3.3 ± 3.6 levels for subjects with incomplete injuries. For subjects with an AIS A grade there was no difference in sensory level change based on upper, middle or low sensory level groups, which had changes of 0.70 ± 2.6 , 0.14 ± 3.06 , and 0.22 ± 2.88 respectively ($P = 0.52$). Among subjects of all AIS grades, at the one-year exam 23.8% of subjects had lost one or more levels, 30.9% stayed the same, and 45.3% improved. Differences were seen between complete and incomplete subjects for gains in sensory level, with incomplete subjects demonstrating greater gains ($P < 0.001$). Among subjects with AIS grade A injuries, at the one year exam 24.2% had lost levels, 36.1% remained at the same level, and 39.6% had improvements (Table 2). In contrast, gains in sensory level were seen in over 50% of subjects whose initial AIS grade was B–D. For subjects with AIS grade A injuries, 86.1% remained within two levels of injury at 1 year. While only 8.2% of subjects with AIS grade A injuries improved three

Table 2 Change in sensory level from initial to 1-year examination by initial AIS grade

Initial AIS grade	<i>n</i>	Sensory level change (%)						
		≤ 3	–2	–1	0	1	2	≥ 3
A	194	5.7	5.2	13.4	36.1	20.1	11.3	8.2
B	34	8.8	8.8	8.8	11.8	17.6	11.8	32.4
C	21	4.8	9.5	4.8	23.8	19.0	9.5	28.6
D	16	12.5	6.3	0.0	18.8	12.5	25.0	25.0

Figure 2 Initial AIS grades by age group.

or more sensory levels, 29.6% of subjects with incomplete injuries did so.

AIS grades

Among the 1-y NE subjects, although AIS grade A at injury was the most common grade in all age groups, the frequency of complete injuries differed by age (Fig. 2). In each of the age groups below 40 years, more than 75% of subjects had AIS A injuries. In contrast, percentage of AIS grade A injuries in the older age groups ranged from 42–72% ($\chi^2 = 16$, $P < 0.01$). AIS grade changes are summarized in Table 3. The number of subjects remaining at grade A was 84.5%, with 7.7% converting to grade B, and 7.7% to motor incomplete (grades C and D). For those originally at grade B, 41.2% remained motor complete, while 55.9% converted to C and D and 2.9% to E. For patients with AIS grade A injury, lower level of injury was related to a greater rate of conversion to a higher AIS grade ($z = -1.80$, $P < 0.05$ Cochrane-Armitage Trend Test, Exact One Sided). Only 1.9% of subjects with upper thoracic injuries converted from AIS grade A to grade D, compared to 3.5% for mid-thoracic injuries and 7.2% for low thoracic injuries.

Subjects with a violent etiology of injury were more likely than subjects with non-violent etiologies to have a complete SCI (85.1% vs. 69.2%; $P < 0.05$). However

subjects with violent and non-violent AIS grade A injuries did not differ in rates of conversion to incomplete (16.1% vs. 14.0%; $P = 0.72$).

Motor scores

LEMS changes from initial exam to 1-y NE were related to initial AIS grade (Fig. 3). Subjects with grade A injuries had the smallest improvement, while grade C subjects had the most. Although AIS grade D subjects had a smaller improvement than the other incomplete injury groups, AIS grade D subjects had the highest LEMS at one year, indicating a ceiling effect. In a Tukey multiple comparisons test, the differences in LEMS change between all AIS grades except B vs. D were significant ($P < 0.05$).

AIS grade A subjects with high thoracic injuries had a smaller increase in LEMS (1.5 ± 7.5 points) compared to subjects with low thoracic injuries (4.1 ± 8.4 points) ($P < 0.05$). The median change in LEMS was 0 points for all three thoracic level groups. More subjects with low thoracic levels had gains in LEMS (32.5%), compared to upper thoracic (3.7%) and middle thoracic (10.5%) injury subjects ($\chi^2 = 13.9$, $P < 0.001$). Only subjects with initial sensory level of T12 had a median change in LEMS > 0 (median change 3.5 points, IQR 0–13 points).

FIM

FIM scores increased the most between admission to rehabilitation and discharge from rehabilitation. However, subjects continued to demonstrate improvement between discharge and one year (Fig. 4). Between rehabilitation admission and one year, AIS grade A subjects improved by 43.6 ± 14.9 points, B by 45.8 ± 14.3 , C by 49.8 ± 15.1 , and D by 48.4 ± 10.1 . Subjects gained between 10–16 FIM points after rehabilitation discharge. The mean FIM score for subjects who had an initial AIS grade of A, B, or C was 28.2 ± 8.0 at admission to rehab, 61.1 ± 13.6 at discharge and 72.7 ± 14.0 at one year.

In univariate analyses, FIM scores at 1 year generally decreased with increasing age and increased with AIS grade (Fig. 5). Subjects with AIS grade A injuries had

Table 3 AIS grades at admission and the 1-year neurological exam

Initial AIS grade	n	One year AIS grade (%)				
		A	B	C	D	E
A	194	84.5	7.7	3.1	4.6	0.0
B	34	20.6	20.6	26.5	29.4	2.9
C	21	0.0	9.5	4.8	81.0	4.8
D	16	0.0	0.0	0.0	87.5	12.5

Figure 3 Initial and 1-year lower extremity motor scores for AIS grades A through D.

the lowest one year FIM scores, while AIS grade D injuries had the highest ($P < 0.05$). FIM scores declined the most by age group in those with AIS grade A and B injuries. In contrast, subjects with AIS grade D injuries had the highest FIM scores and the least variation among age groups. Subjects with a sensory level at T10–12 had significantly higher one-year FIM scores than subjects with T2–5 and T6–9 level injuries ($P < 0.05$). Subjects who had an increase in AIS grade had a one-year FIM score eight points higher than those who did not improve.

The linear mixed effects model of initial AIS grade, high vs. low thoracic level of injury, and age group to predict 1-y FIM score showed that all three variables were significant (Table 4). The model explained 21% of the variance in FIM scores. Compared to subjects with AIS grade A injuries, 1-y FIM scores were 9.8 points higher for AIS C and 16.6 points higher for

Figure 4 FIM score by AIS grade at admission to rehab, discharge from rehab, and one year post-injury.

AIS D subjects. Average 1-y FIM scores ranged from 75.7 for the 14–20 year age group to 65.1 for the 61–70 year age group. Having a low thoracic injury resulted in a 5.7 point greater 1-y FIM score than having a high thoracic injury. An increase in AIS grade accounted for a seven point higher 1-year FIM score than not gaining an AIS grade after adjusting for age, thoracic level of injury and initial AIS grade ($P < 0.001$).

Walking

Subjects with AIS grade A injuries were much less likely to be walking at one year compared to subjects at other AIS grades ($\chi^2 = 115$; $P < 0.001$). Only 5.4% of subjects with AIS grade A injuries were walking at least 50 m, compared to 29.4% of grade B, 69.4% of grade C, and 82.4% of grade D subjects. Similarly, only 7.0% of subjects who presented with LEMS of zero were able to walk at least 50 meters at one year, compared to 68.1% of subjects with nonzero initial LEMS ($\chi^2 = 148$, $P < 0.001$). Higher initial LEMS was associated with better chance of walking at 1 year (Table 5). Subjects with incomplete paraplegia had a better chance of walking with a low initial LEMS than subjects with complete injuries; 20% of those with incomplete injuries and initial LEMS of 0 walked compared to only 2% of subjects with complete injuries.

Sensory level at admission was also a significant factor in recovery of walking. Only 9.5% of subjects with high thoracic paraplegia walked, compared to 27.4% of subjects with low thoracic injuries ($\chi^2 = 21.9$, $P < 0.001$). Among subjects with incomplete injuries, the difference was not significant; 44.7% of those with T2–9 injuries compared with 56.1% of T10–12 subjects could walk at least 50 m ($\chi^2 = 1.2$, $P = 0.27$).

Among all subjects, those above age 50 had higher rates of walking (32.2%) compared to younger subjects

Figure 5 One year FIM score by age and AIS grade.

Table 4 Results of linear mixed effects model of initial factors to predict 1-year FIM score

Effect	Group	Estimate	Standard error	t	P-value
Intercept		57.3	2.8	20.71	<0.0001
Age group	14–20	14.8	3.0	4.92	<0.0001
	21–30	14.8	2.9	5.19	<0.0001
	31–40	11.0	3.0	3.73	0.0002
	41–50	8.8	3.1	2.85	0.0046
	51–60	4.4	3.4	1.29	0.1966
	61–70	0.0			
Initial AIS grade	A	0.0			
	B	3.9	2.0	1.98	0.0481
	C	9.8	2.3	4.27	<0.0001
	D	16.6	3.2	5.22	<0.0001
Thoracic level	T10–12	5.7	1.3	4.3	<0.0001
	T2–9	0.0			

(15.0%) ($P < 0.002$). However, among just subjects with an AIS A grade, the difference was not significant ($P = 0.09$, Fisher's Exact Test). 12.2% of subjects older than 50 compared to 4.6% of younger subjects could walk.

In our logistic regression of ability to walk with age group, AIS grade, and thoracic level group as independent variables, age above 50 was no longer a significant factor ($P = 0.16$) (Table 6). Subjects with high thoracic injuries were less likely to walk compared to subjects with low thoracic injuries ($P < 0.05$). Compared to subjects with AIS grade A injuries, the odds of walking with incomplete injuries were six times better for AIS B, 30 times better for AIS C and 73 times better for AIS D injuries ($P < 0.001$). Having an increase in AIS grade conferred a 9.6 (3.1–30.1) better odds of walking than not having a gain in AIS grade after controlling for initial AIS grade and level of injury.

Discussion

This report updates neurologic and functional outcomes after traumatic paraplegia using SCIMS data of subjects injured between 2000 and 2011. The findings from this report are similar to reports of neurological recovery from the Sygen and EMSCI databases, and from prior analyses of the SCIMS database. Greater differences were seen in functional recovery, with patients being

discharged from rehabilitation at lower functional levels than prior reports,¹⁴ and with prognosis for ambulation less optimistic than previously seen.^{13,15} The SCIMS and EMSCI databases are longitudinal with incomplete follow up, while the Sygen database has more complete follow up but a more selective subject population. The similarity of results for neurological recovery from these different databases is reassuring, suggesting that the findings are not markedly biased.

Neurological recovery

In this report, 15.5% of AIS grade A paraplegia subjects converted to higher grades, with 7.7% to motor incomplete (AIS grade C and D). This was similar to the EMSCI database report by Zariffa where 18.2% of AIS grade A subjects converted to higher grades, and 10.5% converted to motor incomplete,⁷ and the conversion to incomplete and motor incomplete in the Sygen database as reported by Fawcett which had rates of 12.6 and 6.7%, respectively.¹⁶ The conversion rate in paraplegia is less than current rates in persons with tetraplegia, in whom 30% convert to incomplete and 15% to motor incomplete.⁴ The higher rate of conversion from complete to motor incomplete injury for persons with tetraplegia compared to paraplegia was also seen by the EMSCI group.¹⁶

Changes in neurological level for thoracic SCI patients with AIS grade A injuries are determined by sensory testing rather than motor testing. Prior reports indicated that average change in neurological level was negligible, with only a median change of one spinal level.^{7,8} We found a mean change of 0.33 ± 0.21 sensory levels for subjects with AIS grade A injuries, indicating that there is a slight improvement in sensory level. Our absolute change of 1.5 sensory levels in subjects with AIS grade A injuries is in agreement with

Table 5 Percentage of subjects walking by one year based on initial LEMS

Initial LEMS	% walking Complete	% walking Incomplete
0	2.1	20.0
1–9	33.3	54.6
10–19	–	62.5
20–29	–	87.5
30+	–	76.9

Table 6 Odds ratios for walking at 1 year post injury

Parameter	Comparison	Odds ratio	95% CL		P-value
Age >50	Yes vs. No	1.8	0.8	4.0	0.1598
Initial AIS grade	B vs. A	6.0	2.7	13.5	<0.0001
	C vs. A	30.4	12.5	74.0	<0.0001
	D vs. A	72.6	18.5	285.0	<0.0001
Thoracic level	Low vs. High	2.4	1.2	4.9	0.012

the mean of 1.40 levels for light touch and 1.48 for pinprick reported by Harrop using the Sygen database.⁸

At one year, we reported no change in sensory level for 36.1% of subjects with AIS grade A; 86% remained within two levels of initial sensory level. This was quite similar to EMSCI, where 34.8% of subjects with thoracic AIS A injuries had no change in sensory level, and 89.8% remained within two levels of initial. Similarly, we reported 39.7% of patients had a positive change in sensory level, slightly greater than the 33.05% reported for the EMSCI database and 33.0% reported for the Sygen database.^{7,8} We found that subjects with incomplete thoracic level SCI had greater improvements in sensory level than those with complete injuries, which was not examined in reports on EMSCI or Sygen data.

The increase in LEMS was similar to the 1999 report of SCIMS data.⁵ Although few subjects with AIS grade A had an increase in LEMS, those with thoracic injuries between T10 and T12 had a higher likelihood of having some increase in LEMS. More than half the subjects with an initial level of T12 had an increase in LEMS. This is greater than the EMSCI database, in which 40.4% of subjects with low thoracic injuries (T10–12) had increases in LEMS.^{7,8} The difference in results may be due to the different methodologies: the EMSCI report used an ‘all available data’ analysis so that the subjects at the initial and final assessment were not all the same; we only included results for subjects with data at both time points.

The limited neurological recovery for persons with thoracic complete SCI highlights the value of studying this population in clinical trials for neuroprotection and neuroregeneration. More variability in recovery is seen in persons with low thoracic levels of injury. Subjects with complete T10–12 injuries were more likely to convert to incomplete and improve in LEMS than those with higher level thoracic injuries. While it may be desirable to exclude persons with T10–12 injuries from acute clinical trials, this decision comes at a price. The most common thoracic levels of injury are T10–12, and excluding them would make over 40% of patients ineligible for enrollment. Excluding persons

with injury levels of T12 and below would remove those most likely to gain LEMS and make only about 20% of patients with thoracic level paraplegia ineligible.

Functional recovery

The mean rehabilitation length of stay for subjects with thoracic SCI of 50.8 days is almost 6 days shorter than the 56.7 days reported in 1999 by Hall.¹⁴ In 1999, the mean FIM scores for thoracic subjects with AIS grades A, B, and C combined were 32.5 ± 12.0 ($n = 1718$) at admission, 69.3 ± 13.1 ($n = 1869$) at discharge, and 72.2 ± 14.4 ($n = 402$) at one year (Fig. 6).¹⁴ For subjects with thoracic AIS grade A–C injuries we found a 1-year FIM score of 28.2 ± 8.0 at admission to rehab, 61.1 ± 13.6 at discharge and 72.7 ± 14 at 1 year. Although subjects were discharged one week earlier, both this group and the 1999 group recovered to similar FIM scores by one year.

Subjects who had AIS grade A injuries had lower one-year FIM scores compared to subjects with less severe injuries. Furthermore, those in older age groups had lower one-year FIM scores compared to their younger counterparts. This is consistent with prior findings from the SCIMS and EMSCI databases. The EMSCI group reported higher one-year Spinal Cord Independence Measure scores with better AIS grade at

Figure 6 Comparison between 2011 and 1999 SCIMS data of FIM scores at rehabilitation admission, discharge, and 1-year for subjects with paraplegia.

injury,¹⁷ and that older age was associated with poorer functional outcome in patients with motor complete tetraplegia and paraplegia.⁹ Using data from 1988–1996, Cifu *et al.* also found age-related differences in FIM scores after controlling for level and completeness of injury.¹⁸ The lower FIM scores were most pronounced in subjects aged 60 and older compared to younger subjects. We found that the decrease in one-year FIM scores for older age groups was greatest in subjects with motor complete injuries. As the majority of these subjects have little motor recovery, the difference in functional outcomes could be due to the reduced adaptability and strength of older subjects, or to other impairments limiting their use of upper extremities for daily activities.

We found that thoracic level of injury, when dichotomized into high (T2–9) and low (T10–12), was associated with one-year FIM scores. This is in contrast with EMSCI data where thoracic level of injury was not a significant predictor of SCIM score in a linear regression model.⁹ We did not find a difference in FIM scores within the high thoracic group, and the difference between high and low thoracic paraplegia groups was modest (5.7 points). While this may be due to lack of sensitivity of the FIM or the SCIM in thoracic SCI, it may also be due to the fact that there is not much of a functional difference among those with thoracic level injuries of the same severity, at least for basic self care and mobility. This is not the case for cervical SCI, where both the FIM and the SCIM show differences in function for different levels of tetraplegia.^{9,14} Measures that focus on trunk control¹⁹ or seated reaching²⁰ may be better able to detect functional differences in thoracic SCI, and validated measures would be a welcome addition to current assessments.

Walking

Another indicator of functional recovery is the mode of locomotion of the patient. We reported that subjects with AIS grade D injuries were only marginally more likely to walk compared to subjects with AIS grade C at one year (82.4% vs. 69.4%). Kay had reported that at discharge from rehabilitation, subjects with AIS grade D injuries were more likely than subjects with AIS grade C injuries to walk, but their values for both were lower (57.1% vs. 31.3%).²¹ This demonstrates the continued improvement in function between discharge and one year, and that the gap between the AIS C and D groups continues to narrow over the recovery period.

Waters found that 45% of patients with complete thoracic SCI and a 1-month LEMS > 0 were community ambulators at one year, as were 100% of patients with incomplete injuries and a one-month LEMS >

9.¹³ Our results were not as promising, likely due to different populations. Our patients were older than those of Waters *et al.*, with a mean age of 35 years compared to 27 years for Waters.^{13,15} The oldest subject in Waters study population was 52 years old, while 15% of our subjects were over 50 years old. Daverat *et al.* reported that both severity of injury and age at injury were independent predictors of walking at one year post-injury.²² Kay *et al.* found that being older than 50 had a significant negative effect on walking for AIS D subjects, while it was not a factor for AIS C subjects.²¹ Although we expected those in higher age groups to be less likely to walk, we did not find an effect of age on walking after controlling for level and completeness of injury. However the small number of older subjects with incomplete injuries in our sample limited our ability to detect a difference by age.

Significance of change in AIS grade

We found that improvement in AIS grade was associated with a functional benefit both in terms of FIM scores and ambulation. This is an important finding since some investigators have questioned the significance of AIS grade conversion.²³ Improvement in AIS grade was found to be poorly related to recovery of ambulation by the EMSCI group.²³ However they looked at overall conversion for all grades and did not evaluate the odds of walking after AIS conversion controlling for initial AIS grade. We do agree that AIS grade D should not be considered synonymous with ability to ambulate, particularly in older individuals with SCI. Kirshblum *et al.* found that persons who converted from motor complete to motor incomplete between rehabilitation discharge and one year post-injury reported better functional independence and greater social participation than persons who did not convert.²⁴ Although the authors did not look at conversion from AIS grade A to B, they found that persons who were AIS grade A at one year were more likely to use invasive methods of bladder management (Foley or intermittent catheterization) and less likely to report improved health status than persons who were AIS grade B. Thus it is likely that any improvement in AIS grade conveys health benefits, although not necessarily a change in self-care or mobility status.

Study limitations

This study is limited by incomplete follow up and a relatively small sample size for subjects with incomplete SCI. However, while the loss-to-follow-up rate is 60% (39% for the FIM results), we did not find significant differences in demographics between subjects with and

without one-year data. Given this finding and the congruence of our results with other reports in thoracic SCI, we do not believe that loss-to-follow-up significantly affects the results.

Conclusions

This study of traumatic thoracic SCI of the SCIMS database found similar changes in sensory level, LEMS and AIS grades as previous reports from several different sources. There are minimal changes in sensory level and LEMS for complete thoracic SCI above T9, but more variable amounts of recovery below T9. Older persons with SCI are less functional than younger persons at 1-year post injury. Modest differences in FIM scores are seen between those with high vs. low thoracic level injuries, but measures that focus on trunk control are needed to detect functional benefits of having a lower level injury.

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Conflicts of interest None.

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