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Factors Predicting Motor Recovery and Functional Outcome After Traumatic Central Cord Syndrome

A Long-term Follow-up

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Study Design. A prospectively maintained database-generated retrospective review and cross-sectional outcome analysis was performed at a single academic center.

Objectives. To assess the improvement in ASIA motor score (AMS) and secondarily to assess generic health related quality of life (HRQoL) and functional status; correlating these with variables that may predict outcome.

Summary of Background Data. Many variables are potential contributors to motor recovery, patient function, and outcome following cervical trauma. Studies often suffer from low power, short follow-up, heterogeneous cohorts, and use of outcome instruments that are neither valid nor psychometrically sound.

Methods. AMS were collected within 72 hours of the time of injury and again at follow-up by trained examiners. The SF-36 and FIM were administered to all patients at follow-up.

Results. AMS improved from a mean of 58.7 at injury to a mean of 92.3 at follow-up. Bowel and bladder continence was reported by 81% while independent ambulation was reported by 86%. Final AMS was positively correlated with the AMS at injury, formal education, and presence of spasticity at follow-up. Functional status (FIM) was positively correlated with higher AMS at injury, formal education, absence of comorbidities, absence of spasticity, and younger age. Generic HRQoL outcomes (SF-36) were improved in individuals with more formal education, fewer comorbidities, absence of spasticity, and anterior column fractures.

Conclusions. Although the majority of patients improve to an AMS between 90 and 100, many have significant disability and are less functional than the general population. Significant predictive variables include the initial motor score, formal education, comorbidities, age at injury, and development of spasticity. An assessment of more than just the motor score is required to obtain an appreciation of the function and outcomes in this population.

Key words: traumatic central cord syndrome, incomplete spinal cord injury, health-related quality of life, outcomes, function, education, spasticity. **Spine 2005;30: 2303–2311**

Although it is generally assumed that patients with traumatic central cord syndrome (TCCS) experience dramatic neurologic improvement, many face significant functional impairment at long-term outcome.[1–3] Furthermore, a number of features of an individual patient's clinical presentation or treatment have been postulated to predict the degree of eventual impairment and disability. There is little agreement as to which of these variables are the most significant predictors of outcome.

The majority of studies that report on the outcome of TCCS are Class III studies, primarily case series, or comparative studies with historical controls.[1–15] It is difficult to compare between studies because of the variability in techniques of measuring impairment, specifically motor function. Variable scales such as the ASIA motor score or the 6-point Medical Research Council scale have been used.[11] The initial motor score at the time of injury is rarely collected prospectively and may first be measured after some significant motor improvement has already occurred, up to 1 month following injury.[8,12,15]

Reporting functional outcomes is similarly confusing because of the wide variety of instruments used. The Frankel classification,[12,14] the International Standards for the Neurologic Classification of SCI,[3,4,8] the Modified Barthel Index,[12] the Functional Independence Measure (FIM),[3] and other less standardized descriptors have all been reported. The majority of these reports could have greater patient and societal relevance by also reporting measures of generic health-related quality of life (HRQoL).

From the existing literature, there are multiple factors that have been described as prognostic variables in TCCS. These include patient age,[12,15–17] initial ASIA Motor Score,[12] the presence or absence of spasticity,[1,12,15] hyperpathia (a particularly bothersome burning or tingling form of neuropathic pain) present in the early clinical course,[11] as well as the specific pathoanatomic diagnosis (disc herniation, spondylosis, or fracture

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dislocation).[9] Recently, a number of authors have suggested that there are neurologic, functional, and resource-related benefits to the surgical treatment of TCCS.[4–7,9] Unfortunately, these inferences fall well short of a cause-and-effect association secondary to selection bias, low numbers of subjects, difficulty controlling for multiple variables, and the lack of objectively administered standardized validated outcome measures.

Other variables of potential relevance, such as formal education and socioeconomic factors have, to our knowledge, not been studied in patients with TCCS, although they have shown importance in other disease states.[18–20] The resulting lack of agreement on the significance of potential prognostic and treatment variables has led to confusion regarding the optimal therapeutic options, particularly regarding the place of surgery in the treatment of TCCS.

The primary objective of this study was to validly and reliably assess the change in motor function by prospectively measuring motor function from the time of injury (first presentation at an acute care hospital) to long-term follow-up in a cohort of patients who had sustained a TCCS. Secondary objectives of this study were to perform cross-sectional measurements of the patients' functional status and generic HRQoL outcome at long-term follow-up. Finally, we attempted to record a number of premorbid, injury, and treatment variables and assess their association with the patient's motor recovery, ultimate functional status, and HRQoL outcomes. By using the prospective collection of a validated and standardized measurement of impairment and correlating this to psychometrically sound and validated outcome instruments, we attempted to describe the health status of patients remote from a TCCS injury and identify predictors of improvement in impairment, function, and general HRQoL.

■ Materials and Methods

Study Protocol. Inclusion criteria consisted of patients with a primary diagnosis of TCCS defined as a cervical spinal cord injury that produces disproportionately greater weakness in the upper limbs than the lower limbs and is associated with sacral pin-prick or voluntary motor sparing. To be included, patients had to be admitted to the Acute Spinal Cord Injury Unit at the Vancouver General Hospital within 72 hours of injury and have an initial ASIA Motor Score (i-AMS)[21] performed by a spine unit physiotherapist at the time of admission. Furthermore, they had to have the opportunity to benefit from an inpatient or outpatient rehabilitation program. A minimum 2-year follow-up was required.

Patients were excluded from this study if they had prohibitive medical comorbidity (cancer, multiple sclerosis, severe liver or kidney failure, diabetes, *etc.*), organic brain disease or dementia, multiple trauma or other injuries that would influence function, or inflammatory arthritis. Patients were also excluded if they were unable to fill out the required outcome instruments.

Patient Data. A prospectively maintained database identified 114 patients with the primary diagnosis of traumatic cervical central spinal cord injury as diagnosed by the attending spine surgeon. Of these, 13 patients had died, 3 were hospitalized and too sick for follow-up, 16 could not be located, and 12 patients declined participation. This left 70 patients (61%) that were examined for follow-up ASIA motor score (f-AMS) and completed all the outcome questionnaires. The patients that were not studied (died, sick, not located, and declined) were older than the 70 patients that are included (average age of included patients = 51; excluded patients = 62); otherwise, the excluded patients did not differ significantly from the study population.

Demographic data are summarized in Table 1. Eighty-one percent of the patients were male with an average age of 51 years, followed for an average of 70 months. The range of ages is presented in Figure 1. The spinal level of injury is outlined in Figure 2; it is notable that 3 patients had more than one level of cervical injury. Sixty-five percent of the patients had evidence of a cervical spine fracture or traumatic disc protrusion while the remainder had cervical stenosis (Table 1). The patient's diagnosis was categorized as 1) spondylosis without fracture (including traumatic disc herniation), 2) anterior column (vertebral body) fracture (including odontoid fracture), or 3) posterior element fracture based on the premise that these three "categories" of injury represented different injury mechanisms.

The energy associated with the injury was classified as either low or high energy based on a classification produced by the American College of Surgeons, Committee on Trauma.[22] The mechanism of injury was classified as high energy in 39% (Table 2).

Therapeutic Principles. Clinical evaluation and conventional imaging (plain radiographs, CT-myelogram, and MRI) were used by each of five full-time spine surgeons (two neurosurgeons and three orthopedic surgeons) to determine a treatment plan. Patients that met the NASCIS II protocol[23] were prescribed steroids. The most common reason that patients did not receive the steroid protocol was referral beyond the 8-hour window. Generally, unstable fractures and fracture subluxations were treated with surgical decompression and stabilization within 72 hours. Fifty-nine percent of all patients were treated operatively. Patients with no evidence of axial skeletal instability were placed in a cervical orthosis (Philadelphia collar) and mobilized. Indications for delayed surgery included a

Table 1. Patients With Traumatic Central Cord Syndrome: Demographic Characteristics

Variable	Mean ± SD	No. of Patients	%
Age (yr)	51 ± 18		
Follow-up interval (mos)	70 ± 34		
Diagnosis			
Degenerative change; no fracture		25	35
Anterior column fracture		18	26
Posterior element fracture		23	33
Odontoid fracture		2	3
Traumatic disc		2	3
NASCIS II protocol		32	46
Male		57	81
Brown-Sequard syndrome		11	16
Surgical treatment		41	59

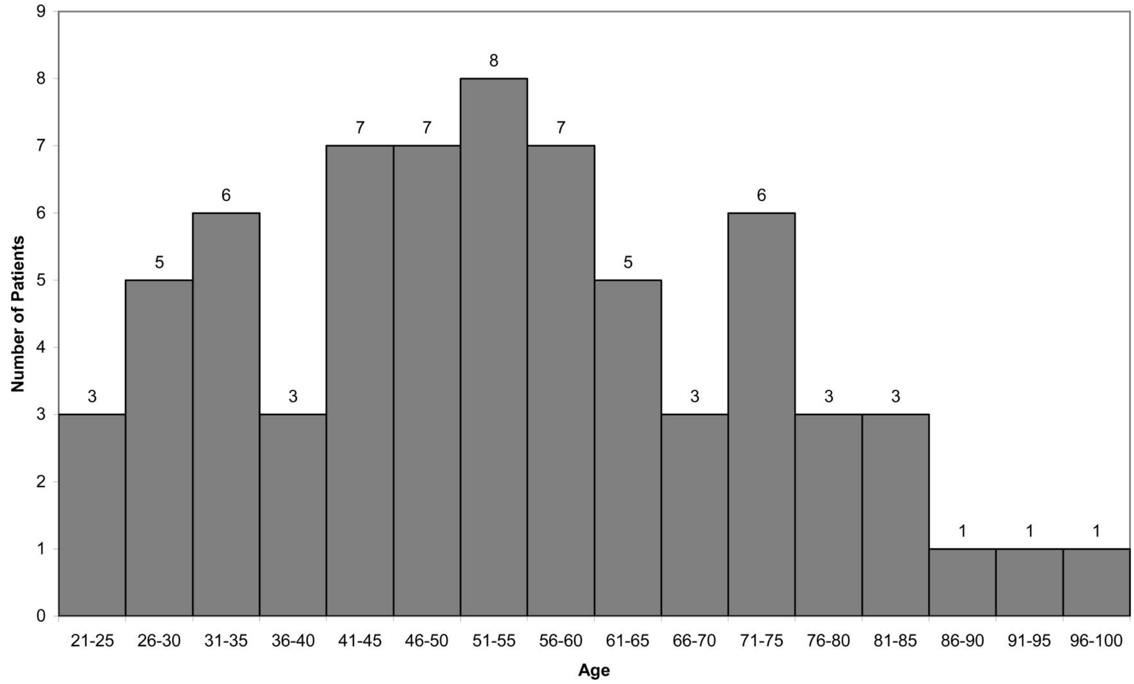

Figure 1. Age histogram of central cord patients.

prolonged neurologic plateau or neurologic deterioration in the presence of persistent cord compression on MRI or CT myelogram. Surgical treatment consisted of either anterior or posterior decompression with stabilization when indicated. All patients underwent standard aggressive postoperative inpatient and outpatient rehabilitation.

Outcome Assessments. Institutional Ethics approval was obtained from Vancouver General Hospital and the University of British Columbia to collect the data and to contact eligible patients for the purpose of performing the f-AMS examination and administering the HRQoL questionnaires. Informed consent was obtained from each participant in this study.

Prospective collection of the i-AMS was accompanied by the collection of demographic and treatment variables, such as age, gender, treatment, steroid administration, spinal column injury level and pattern, and length of hospital stay (Table 1).

The level of formal education was classified on an ordinal scale and is detailed in Table 3, along with marital status. These variables were stored in a customized, fully relational, locally designed spine database, "Vertebase." The spine surgeons recorded the database information weekly during peer-review rounds to ensure accurate diagnostic coding and complete collection of data. An independent observer verified the data by reviewing both the database and patients' charts. All of the questionnaires were administered in person by a trained

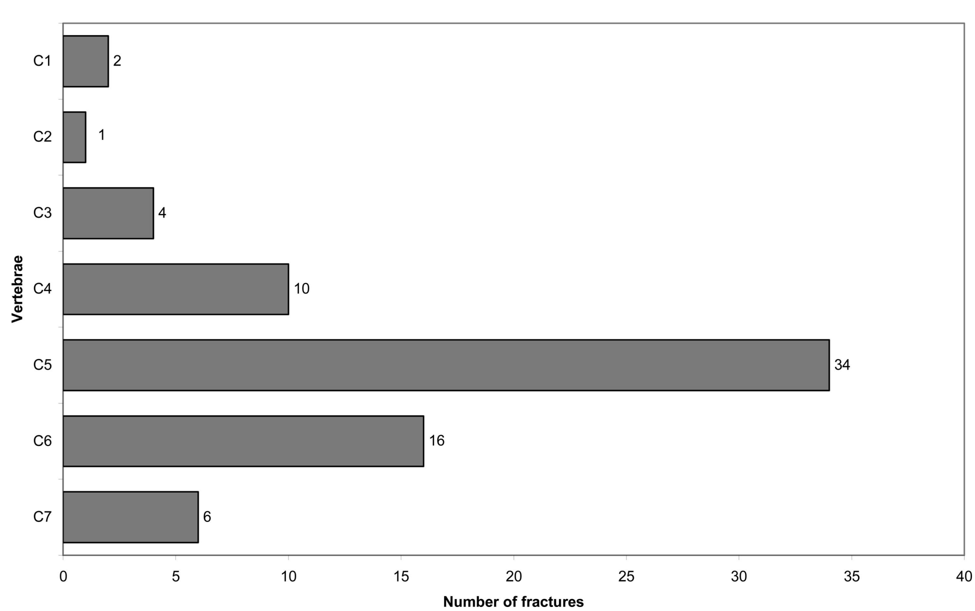

Figure 2. Spinal level of injury histogram of central cord patients. Some patients had fractures at multiple levels.

Table 2. Mechanism of Central Cord Injury, With Stratification Into High- and Low-Energy Categories Based on a Classification Produced by the American College of Surgeons, Committee on Trauma

Variable	Total No.	High Energy	Low Energy
MVA	26	16	10
Fall			
Standing	13		13
Height >3 ft	7	7	
Sports			
Skiing	6		6
Diving	4		4
Bicycle	3		3
Trampoline	2		2
Hockey	1		1
Assault	4		4
Pedestrian MVA	2	2	
Logging—struck by tree	2	2	
Total no.	70	27	43
%		39	61

MVA = motor vehicle accident.

physiotherapist at the time of the follow-up neurologic examination.

The presence or absence of spasticity was assessed at the time of follow-up. Spasticity was defined as a syndrome, including one or more of the following: a velocity-dependent increase of tonic stretch reflexes, increased tendon reflexes, or other release phenomena such as increased flexor reflexes/flexor spasms.

ASIA Motor Score (i-AMS, f-AMS, and Δ-AMS). The initial ASIA motor score (i-AMS) was performed by a trained physiotherapist on the ASCIU within 72 hours of injury. The f-AMS was similarly collected by a spine unit physiotherapist, trained in the ASIA grading system. The change in AMS (Δ-AMS) was calculated by subtracting the i-AMS from the f-AMS. The physiotherapist evaluator traveled throughout the province to examine individual patients and was blinded to the patient's previous motor score, baseline variables, and treatment at the time of evaluation.

Short Form-36 (SF-36). The SF-36 is a generic HRQoL questionnaire. It consists of 36 items and assesses 8 health dimensions. Physical and mental component scores (PCS and MCS) can be derived with the physical component score (PCS) ranging from 73 (high level of functioning) to 8 (low level of functioning) and the mental component score (MCS) ranging from 74 (excellent) to 10 (poor). This questionnaire has been found to be reliable, valid, and responsive when administered over the phone or by mail.

Table 3. Level of Education Achieved and Marital Status at Time of Injury in Patients With Traumatic Central Cord Injuries

	No.	Percentage
Education		
Less than high school	16	24.2
High school graduate	20	30.3
Some college	10	15.2
College graduate	13	19.7
Postgraduate	7	10.6
Martial status		
Married	27	52.4
Common-law	4	7.8
Divorced/separated	7	13.7
Widowed	4	7.8
Single	9	17.6
Unknown	19	

Functional Independence Measure (FIM). The FIM assesses disability by reporting on motor skills through 13 subscales and cognitive skills through 5 subscales, thus creating a motor domain with its motor score (FIM MS) and a cognitive domain with it's cognitive score (FIM CS). The FIM has been found to be reliable and valid in patients with spinal cord injury.[24–26]

Others. A 14-question comorbidity index, scored from 0 to 100 was used from the AAOS/NASS cervical spine questionnaire.[27] Patients were asked one question to assess their overall quality of life on a scale of 1 to 7 and one question to assess their level of satisfaction with their current symptoms on a scale of 1 to 5.

Statistical Analysis. A descriptive statistical analysis was performed for all quantitative and categorical variables. Changes in motor score from admission to cross-sectional follow-up were evaluated using a paired *t* test; 95% confidence intervals were constructed for the mean difference between these scores. Analyses were performed to assess the association between the primary outcome (Δ-AMS) and specifically selected independent variables that could potentially influence this outcome (Wilcoxon's rank sum test). Regression modeling was performed using the following dependent variables: f-AMS, Δ-AMS, FIM MS, and SF-36 PCS. Independent variables analyzed include age at injury, mechanism of injury, diagnosis (divided into fractures and no fracture), treatment (surgical or nonoperative), spasticity, formal education, and comorbidities.

Results

Impairment (ASIA Motor Score, AMS)

At the time of injury, the i-AMS was an average of 58.7 with a SD = 27.5 and a range from 2 to 96. At follow-up (mean, 70 months; range, 24–143 months) the f-AMS was a mean of 92.3 (median, 98.0); and although the range was 39 to 100, the 25th and 75th percentiles were 90.0 and 100, respectively. Although the i-AMS values were normally distributed, the f-AMS had a skewed, nonparametric distribution. The average change in AMS (Δ-AMS) between injury and follow-up was 33.2 with a standard deviation of 22.8 and a range of −6 to 88. Table 4 presents the various impairment measurements.

Regression analysis revealed that f-AMS was most strongly predicted by the i-AMS ($P = 0.0001$) and formal education ($P = 0.004$). The f-AMS was higher when both the i-AMS and level of formal education achieved were greater. As one would expect, the Δ-AMS was significantly larger when the i-AMS was lower ($P = 0.0001$). A higher f-AMS and larger Δ-AMS were more likely to be present in patients with spasticity at follow-up examination ($P = 0.0003$ and $P = 0.006$, respectively). Although there was a trend, as seen in Table 5, suggesting that advancing age was associated with lower f-AMS, this did not reach significance ($P = 0.30$).

Table 4. Impairment (ASIA Motor Score [AMS]) at Time of Injury and at Cross-sectional Follow-up Assessment

Impairment	Mean ± SD	At Injury (mean ± SD)	At Follow-up Mean ± SD	At Follow-up Median	At Follow-up 25th–75th Percentage
Upper limb AMS		25.9 ± 12.8	45.2 ± 7.1	48.0	43.0–50.0
Lower limb AMS		32.7 ± 16.3	47.0 ± 5.2	50.0	46.0–50.0
Total AMS		58.7 ± 27.5	92.3 ± 11.6	98.0	90.0–100.0
Change in AMS (follow-up, injury)	33.2 ± 22.8				
Upper limb change in AMS	19.1 ± 10.5				
Lower limb change in AMS	14.2 ± 14.6				

Functional Outcome

In the complete group of 70 patients, the mean FIM MS was 83.8 (SD = 15.3) while the mean FIM CS was 34.6 (SD = 1.1). Although no standardized assessment of bowel and bladder function or ambulation occurred at the time of injury, simple observation of our patients identified that these functions generally improved over time. At follow-up, 57 patients (81%) reported being continent with respect to bowel and bladder function, while 60 patients (86%) reported being capable of independent ambulation. At follow-up examination, 41 patients (59%) were identified as having significant spasticity.

A regression analysis revealed a higher FIM MS with younger age at injury ($P = 0.0009$), suggesting a higher level of function in younger patients. Spasticity was associated with a lower (worse function) FIM MS ($P = 0.007$).

The FIM motor score was higher at follow-up in patients who were treated surgically ($P = 0.03$). No other treatment effect could be identified (Table 6).

General HRQoL Outcomes

The reporting of generic HRQoL revealed that the mean PCS of the SF-36 was 42.4 (SD = 12.3), while the mean MCS was 52.4 (SD = 10.6). The normative data available for SF-36 facilitate comparisons between the TCCS population and healthy age-matched Canadians. The SF-36 PCS of our patients at follow-up was significantly lower than that of the normative sample ($P < 0.0001$). The MCS of our patients at follow-up was not significantly different from the normative sample.

The SF-36 PCS summary scores were significantly lower in those patients who had spasticity at follow-up ($P = 0.03$). A regression analysis performed with the SF-36 PCS as the dependent variable revealed that a higher formal education, absence of comorbidities, and a diagnosis of anterior column fracture were strong predictors of improved PCS scores at follow-up ($P = 0.0000$, 0.009, and 0.03, respectively).

Comorbidity was reported in the TCCS patients at a mean of 5.4 with a SD of 5.54 and range from 0 to 26, suggesting that this would generally be viewed as a healthy population. Those patients with higher comorbidity scores also scored lower on the SF-36 PCS ($P = 0.0086$) and the FIM MS ($P = 0.04$). Twenty-four patients (34%) reported no associated comorbidity.

The median quality of life score was 6, out of a scale of 1 (poor) to 7 (excellent) (Figure 3). The median symptom satisfaction score was 4 on a scale of 1 (very dissatisfied) to 5 (very satisfied). Although the quality of life scores was generally high, the symptom satisfaction, as seen in Figure 4, revealed 24 patients (34%) who expressed significant dissatisfaction with their symptoms. Both the symptom satisfaction and quality of life scores are above average; however, these scores, while favorable, are only descriptive as there were no preoperative values or normative data with which to compare.

Other variables such as the NASCIS II steroid protocol, Brown-Sequard pattern, mechanism of injury (motor vehicle accident, fall, sports, *etc.*), high- or low-energy injury type, diagnosis (spondylotic stenosis without fracture, anterior column fracture, posterior element fracture), and gender failed to demonstrate any association with function, motor score, or HRQoL.

Table 5. Follow-up ASIA Motor Scores Stratified Into Various Age Groups (Age at Injury)

Age (yr)	Mean AMS ± SD
20–34	95.35 ± 8.7
35–50	93.95 ± 8.5
51–64	89.47 ± 17.26
65+	88.26 ± 13.85

■ Discussion

Traumatic central cord syndrome is characterized by an incomplete tetraplegia with disproportionate upper *versus* lower extremity weakness. The clinical characteristics of this syndrome include predominantly distal upper extremity weakness, sensory loss, as well as a variable degree of bladder, bowel, and sexual dysfunction.[3,5,8,12–14,17,22] Central cord injuries are the most common incomplete spinal cord injury with a reported incidence varying from 15.7% to 25% of all spinal cord injuries.[1,11]

Impairment

The primary goal of this study was to prospectively measure the AMS within 72 hours of the time of injury and again at cross-sectional follow-up at an average of almost 6 years postinjury. We used examiners who are trained in the application of the AMS grading system.

Table 6. Regression Analysis With Final Motor Score (f-AMS), Functional Independence Measure (FIM-MS), and Short Form-36 (SF-36 PCS) Outcome Measures

	Dependent (outcome) Variables					
	Final ASIA Motor Score		Functional Independence Measure (FIM) Motor Score		Short Form-36 Physical Component Score	
Independent (predictor) Variables	Regression Coefficient (beta)	*P*	Regression Coefficient (beta)	*P*	Regression Coefficient (beta)	*P*
Initial ASIA Motor Score	0.45	0.0001				
Age at injury	−0.11	0.3	−0.34	0.0009	−0.11	0.3
Low-energy mechanism	0.02	0.9	−0.03	0.8	−0.001	0.9
High-energy mechanism	0.15	0.1	−0.08	0.4	−0.12	0.2
Diagnosis: spondylosis	0.02	0.8	0.05	0.6	−0.03	0.8
Diagnosis: fracture	0.05	0.7	0.03	0.8	0.22	0.03
Surgical treatment	0.08	0.4	0.22	0.03	0.08	0.4
Brown-Sequard syndrome	0.01	0.9	−0.13	0.2	0.05	0.6
Spasticity	−0.39	0.0003	−0.27	0.007	−0.21	0.03
Level of formal education	0.43	0.0001	0.23	0.02	0.43	0.0000
Comorbidities	0.11	0.25	−0.21	0.04	−0.26	0.009

The validity and reliability of the AMS have been demonstrated in the literature.[29–31] In our study, patients with TCCS generally exhibited dramatic improvements in AMS from an average i-AMS of 58.7 to a median f-AMS of 98.0, with the majority falling between 90 and 100.

The combination of AMS performed within 72 hours of injury and again at long-term follow-up, both performed by independent examiners, is unique to this study. We have identified improvements in AMS similar to those of other studies where more variability was present in the time points and quality of AMS measurement. We have carefully validated the findings of others: that there is a dramatic improvement in AMS in this population.

In this study, we confirmed the intuitive finding that the best predictor of final motor score is the initial motor score at the time of injury. Surprisingly, however, the next most consistent predictor of motor improvement and high motor scores at follow-up was the level of formal education attained by the patient. Although level of education did not significantly influence initial motor score, a higher level of education correlated strongly with motor score improvement and higher final motor score.

Function

Despite a relatively dramatic improvement in motor scores, others have reported poor functional outcomes

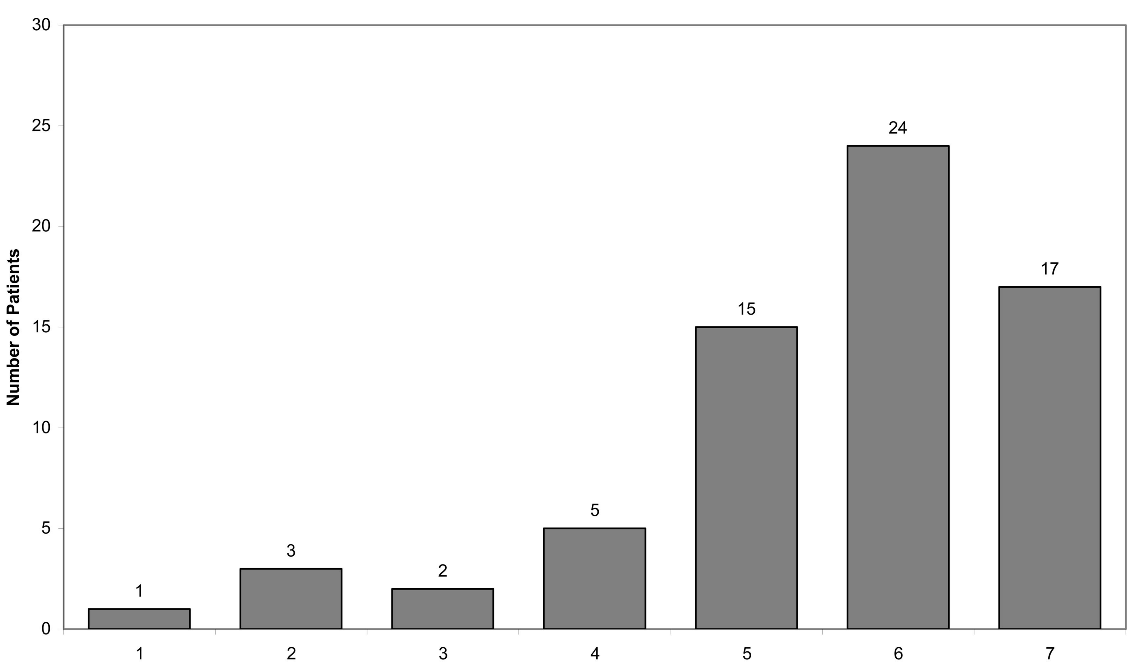

Figure 3. Quality of life histogram where patients are asked: "How would you rate your overall quality of life during the past week from 1 (very poor) to 7 (excellent)?"

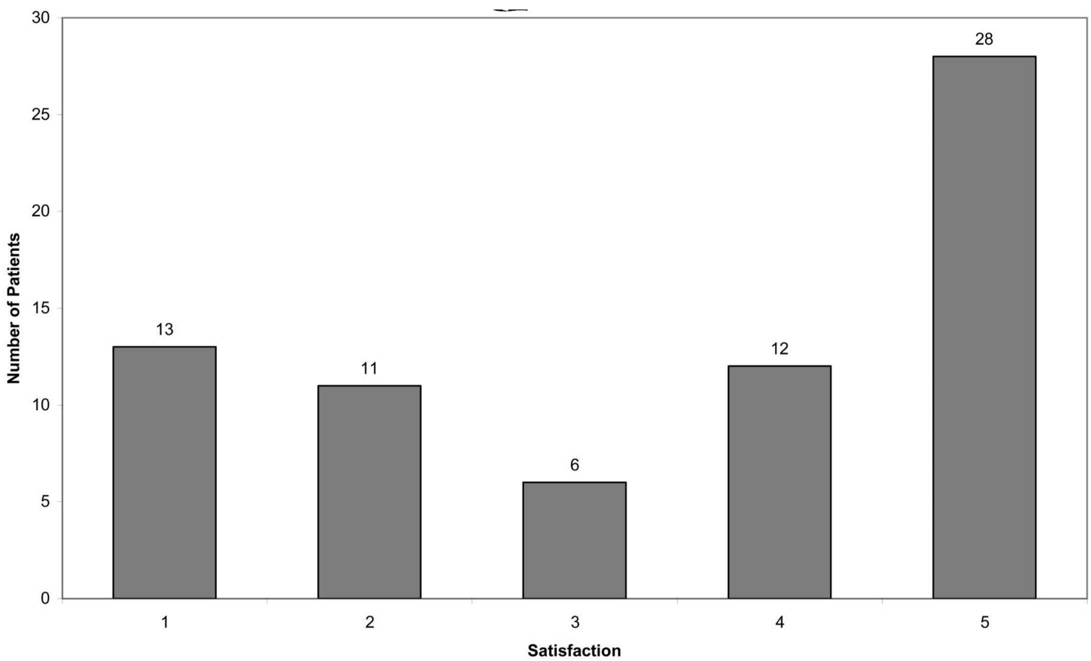

Figure 4. Symptom satisfaction histogram where patients are asked: "If you had to spend the rest of your life with the symptoms you have right now, how would you feel about it? From 1 (very dissatisfied) to 5 (very satisfied)".

in this patient population. Bosch *et al*[1] reported poor outcomes in more than 40% of their conservatively treated patients, with independent ambulation present in 57% and only 43% regaining functional use of their hands. The detailed functional assessments performed by Bridle *et al*[2] confirmed poor hand function and identified fatigue as a significant concern.

Our descriptions of functional outcomes (FIM) serve to record the functional disability that these individuals experience in relation to both injured and healthy individuals in the population. A regression analysis, using these outcomes as dependent variables, identified several independent variables that influenced outcome. Improved functional outcomes were seen with advanced formal education, younger age, absence of spasticity, and with surgical treatment.

HRQoL

The median satisfaction of our patients was high (4 on a 1–5 scale) and the quality of life they reported was also high (6 on a 1–7 scale). A cursory assessment of the responses to these questions would miss the significant ongoing impairment and disability in this population. When asked how they would feel if they had to spend the rest of their life with their current symptoms, 35% of the patients answered that they would be either very or somewhat dissatisfied.

Our findings, that this population of patient scores were significantly worse than a normative sample on validated and standardized outcome instruments such as the SF-36 PCS, further confirm and quantify their impaired HRQoL. From a cognitive and "mental health" point of view, the mean SF-36 MCS of the patients in our study does not differ from that of the general population, suggesting that, although they experience significant physical limitations, these patients have psychologically adjusted to their postinjury state.

Predictive Variables

Formal Education. Level of education was a very strong predictor of improved motor recovery, function, and HRQoL. Formal education is a surrogate measure of socioeconomic status and has been shown to correlate with disability and disease severity in several other conditions such as rheumatoid arthritis, inflammatory bowel disease, and back pain.[18–20] To our knowledge, level of education as a predictor of motor recovery and functional outcome has not been previously reported in this population. It appears to be a significant predictor of outcome and should be reported and controlled for in subsequent studies in this population.

Spasticity. Spasticity appeared to be present in those individuals who had the most dramatic improvements in their motor scores but was negatively related to almost all outcome measures, including the SF-36 PCS and the FIM. Tow *et al*[15] reported lower functional scores on the modified Barthel Index in spastic patients and identified 20% of the 81 patients in their study who required medications for spasticity. Bosch *et al*[1] similarly identified spasticity as a negative influence on function. Newey *et al*,[3] on the other hand, did not identify spasticity as a predictor of functional outcome.

In the current study, those patients who experienced significant motor improvement, were most likely to be plagued by spasticity, and thus were not able to achieve the functional benefits that one would expect given their relatively high motor scores. Further studies are needed to more precisely quantify spasticity as an important variable and carefully consider the extent to which spasticity may negatively modify the functional outcome of what is otherwise seen as a dramatic motor improvement.

Age. Several authors have identified an age-related difference in outcomes.[16,17,32] Newey *et al*[3] reported that patients over 70 years of age at injury did poorly; however, only had 3 patients over age 70 in their study. By analyzing age at injury as a separate variable, independent of i-AMS, we did not show a significant association with motor improvement. We did, however, identify advanced age as a predictor of increased disability as measured by the FIM. The influence that others have attributed to age may be a reflection of the interaction of other variables such as i-AMS, presence or absence of comorbidities, and the energy and type of injury.

Surgical Treatment. The treatment of central cord syndrome remains controversial. Historically, this injury has been treated nonoperatively. Recently, several papers in the literature have suggested potential benefits of early surgical treatment in selected cases[4,7,10] leading to controversy and wide variations in management.[5]

Brodkey *et al*[4] described 7 patients with acute CCS in which surgical decompression was performed followed by rapid improvement. Bose *et al*[4] compared 14 surgical with 14 nonoperative patients retrospectively. The surgical group had higher motor scores at discharge; however, the follow-up was short (average, 50 days) and significant selection bias limited their conclusions. Chen[6] concluded that surgery resulted in more rapid neurologic recovery than conservative treatment, although there was no difference in recovery by 2 years.

In the current study, using multivariate regression techniques to control for other variables, we were able to identify a significant improvement in the FIM MS in the surgically treated patients. Given that surgery was reserved for mechanically unstable (high-energy) injuries and those patients who failed to improve neurologically (plateau or neurologic deterioration), there appears to have been a bias whereby patients who received surgery showed less recovery potential at the outset than those treated conservatively. Surgery did not seem to affect any of the other outcomes, nor did it significantly improve AMS. The role and timing of surgical stabilization and decompression are yet to be defined in this patient population.

Other. It is intuitive that individuals with comorbidity will have a lower functional outcome. We identified lower scores on the SF-36 PCS and the FIM Physical Component Scores when patients had concomitant medical comorbidities.

Our study identified many variables that did not influence motor or functional recovery. These include gender, Brown-Sequard pattern of neurologic loss, diagnosis, mechanism of injury (high- and low-energy), steroid administration, or injury level.

Although this study benefits from the use of valid, reliable, and psychometrically sound outcome instruments, prospective motor score collection from injury to follow-up, and appropriate power to support its conclusions, the authors recognize several limitations. A single cross-sectional outcome assessment at follow-up does not allow for the identification of change, specifically deterioration over time. Bosch *et al*[1] reported neurologic deterioration in 24% of the 42 patients that were followed over 10 years. The functional deterioration that may follow initial neurologic recovery is concerning and can only be identified by performing serial examinations. We acknowledge that the time from injury to follow-up varies among our patients from 2 years to almost 12 years. We also recognize that there may be a selection bias in the patients that we treated surgically, although it was those who failed to show neurologic improvement who were considered for surgery. Finally, several relationships were found with regression modeling, but these must be interpreted with caution as they are mere associations rather than true cause-and-effect findings. We acknowledge analyzing several dependent variables and thus consider our findings as strong associations that generate hypotheses and require further study.

■ Conclusion

We have reported on the ASIA motor score improvement in a cohort of 70 patients who were followed from the time of injury to follow-up between 2 and 12 years following injury. Although a high proportion of patients have motor scores between 90 and 100, motor score alone does not adequately describe function and quality of life in these patients. Future studies in this patient population should report on the patients' socioeconomic status and should accurately assess spasticity as these were both identified as strong predictors of outcome. Although retrospective cross-sectional outcome analyses such as this study may identify associations, there is an urgent need to explore the role and timing of surgery in this patient population through well-designed prospective studies.

■ Key Points

- Although motor recovery is dramatic in central cord injuries, motor score alone does not adequately describe function and quality of life at long-term evaluation.
- Motor recovery is improved in patients with higher motor scores at the time of injury, more formal education, and spasticity at follow-up.

• Spasticity at follow-up is correlated with significant improvement in motor score but leads to less satisfactory function and lower health-related quality of life outcomes.
• Variables that did not appear to influence motor recovery, function, or health-related quality of life include steroid administration, mechanism of injury, specific injury diagnosis, the presence of a Brown-Sequard syndrome, and gender.

References

1. Bosch A, Stauffer ES, Nickel VL. Incomplete traumatic quadriplegia: a ten-year review. *JAMA* 1971;216:473–8.
2. Bridle MJ. Long term function following the central cord syndrome. *Paraplegia* 1990;28:178–85.
3. Newey ML, Sen PK, Fraser RD. The long-term outcome after central cord syndrome: a study of the natural history. *J Bone Joint Surg Br* 2000;82:851–5.
4. Bose B, Northrup BE, Osterholm JL, et al. Reanalysis of central cervical cord injury management. *Neurosurgery* 1984;15:367–72.
5. Brodkey JS, Miller CF Jr, Harmody RM. The syndrome of acute central cervical spinal cord injury revisited. *Surg Neurol* 1980;14:251–7.
6. Chen TY, Lee ST, Lui TN, et al. Efficacy of surgical treatment in traumatic central cord syndrome. *Surg Neurol* 1997;48:435–40.
7. Chen TY, Dickman CA, Eleraky M, et al. The role of decompression for acute incomplete cervical spinal cord injury in cervical spondylosis. *Spine* 1998;23:2398–403.
8. Dai L, Jia L, Ni B, et al. Diagnosis and treatment of acute central cervical cord injury. *Chin Med J* 1998;111:351–3.
9. Dai L, Jia L. Central cord injury complicating acute cervical disc herniation in trauma. *Spine* 2000;25:331–5.
10. Guest J, Eleraky MA, Apostolides PJ, et al. Traumatic central cord syndrome: results of surgical management. *J Neurosurg Spine* 2002;97:25–32.
11. Merriam WF, Taylor TK, Ruff SJ, et al. A reappraisal of acute traumatic central cord syndrome. *J Bone Joint Surg Br* 1986;68:708–13.
12. Roth EJ, Lawler MH, Yarkony GM. Traumatic central cord syndrome: clinical features and functional outcomes. *Arch Phys Med Rehabil* 1990;71:18–23.
13. Schneider RC. The syndrome of acute central cervical spinal cord injury: with special reference to the mechanisms involved in hyperextension injuries of the cervical spine. *Neurosurgery* 1954;11:546–77.
14. Shrosbree RD. Acute central cervical spinal cord syndrome: aetiology, age incidence and relationship to the orthopaedic injury. *Paraplegia* 1977;14:251–8.
15. Tow AM, Kong KH. Central cord syndrome: functional outcome after rehabilitation. *Spinal Cord* 1998;36:156–60.
16. Penrod LE, Hegde SK, Ditunno JF Jr. Age effect on prognosis for functional recovery in acute, traumatic central cord syndrome. *Arch Phys Med Rehabil* 1990;71:963–8.
17. Rand RW, Crandall PH. Central cord syndrome in hyperextension injuries of the cervical spine. *J Bone Joint Surg Am* 1962;44:1415–22.
18. Casellas F, Lopez-Vivancos J, Casado A, et al. Factors affecting health related quality of life of patients with inflammatory bowel disease. *Qual Life Res* 2002;11:775–81.
19. Hagen KB, Holte HH, Tambs K, et al. Socioeconomic factors and disability retirement from back pain: a 1983–1993 population-based prospective study in Norway. *Spine* 2000;25:2480–7.
20. Uhlig T, Hagen KB, Kvien TK. Current tobacco smoking, formal education, and the risk of rheumatoid arthritis. *J Rheumatol* 1999;26:47–54.
21. American Spinal Injury Association. *International Standards for Neurological Classification of Spinal Cord Injury*, revised. Chicago, IL: American Spinal Injury Association, 2002.
22. Committee on Trauma. *Resources for the Optimal Care of the Injured Patient*. Chicago: Committee on Trauma, 1999.
23. Bracken MB, Shepard MJ, Collins WF, et al. 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* 1990;322:1405–11.
24. Granger CV, Hamilton BB, Linacre JM, et al. Performance profiles of the functional independence measure. *Am J Phys Med Rehabil* 1993;72:84–9.
25. Karamehmetoglu SS, Karacan I, Elbasi N, et al. The functional independence measure in spinal cord injured patients: comparison of questioning with observational rating. *Spinal Cord* 1997;35:22–5.
26. Stineman MG, Hamilton BB, Goin JE, et al. Functional gain and length of stay for major rehabilitation impairment categories: patterns revealed by function related groups. *Am J Phys Med Rehabil* 1996;75:68–78.
27. Daltroy LH, Cats-Baril WL, Katz JN, et al. The North American Spine Society lumbar spine outcome assessment instrument: reliability and validity tests. *Spine* 1996;21:741–9.
28. Dvorak MF, Fisher CG. Central cervical cord injury in the presence of cervical spondylotic stenosis. In: Chapman JR, ed. *State of the Art Reviews in Spine*: *Spinal Cord Injuries*. Philadelphia: Hanley & Belfus, 1999.
29. Cohen ME, Ditunno JF Jr, Donovan WH, et al. A test of the 1992 International Standards for Neurological and Functional Classification of Spinal Cord Injury. *Spinal Cord* 1998;36:554–60.
30. Jonsson M, Tollback A, Gonzales H, et al. Inter-rater reliability of the 1992 International Standards for Neurological and Functional Classification of Incomplete Spinal Cord Injury. *Spinal Cord* 2000;38:675–9.
31. Priebe MM, Waring WP. The interobserver reliability of the revised American Spinal Injury Association standards for neurological classification of spinal injury patients. *Am J Phys Med Rehabil* 1991;70:268–70.
32. Dai LY. Acute central cervical cord injury: the effect of age upon prognosis. *Injury* 2001;32:195–9.