Recent Trends in Mortality and Causes of Death Among Persons With Spinal Cord Injury

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ABSTRACT. DeVivo MJ, Krause JS, Lammertse DP. Recent trends in mortality and causes of death among persons with spinal cord injury. Arch Phys Med Rehabil 1999;80:1411-19.

Objective: To identify and quantify trends in mortality and causes of death among persons with spinal cord injury.

Design: Cohort study.

Setting: Model spinal cord injury care systems and Shriner's Hospitals spinal cord injury units throughout the United States.

Patients: A total of 28,239 consecutive persons admitted to the model system or to a Shriner's Hospital within 1 year of injury.

Main Outcome Measure: Length of survival and cause of death.

Results: Among persons who were admitted to the model system within 1 day of injury, the odds of dying during the first postinjury year were reduced by 67% for persons injured between 1993 and 1998 relative to persons injured between 1973 and 1977 after adjusting for trends in age, gender, race, neurologic level of injury, Frankel grade, ventilator status, etiology of injury, sponsor of care, and model system where treatment occurred. However, mortality rates after the first anniversary of injury, which had also been declining from 1973 to 1992, increased 33% for persons injured between 1993 and 1998 relative to persons injured between 1988 and 1992. Respiratory disease was the only cause of death after the first anniversary of injury for which the relative odds increased meaningfully during the latest time period (76% increase over 1988-1992 compared to all other causes).

Conclusion: While great improvements in life expectancy have been achieved since the Model SCI Systems program began, current data support the need for renewed efforts to improve the prevention and treatment of the complications of spinal cord injury.

IN THE PAST SEVERAL decades, acute and long-term survival rates for persons with spinal cord injury (SCI) have improved dramatically,[1-16] although life expectancy of most individuals with SCI remains below normal (ie, the life expectancy of a person from the general US population of the same age, gender, and race who does not have an SCI).[15] Mortality rates are significantly higher in the first year after injury, particularly for more severely injured individuals.[6,12,15,17-20] However, average life expectancy increases significantly for individuals who survive the first year.[21]

Several prognostic factors are related to length of survival, including demographic, injury, and psychosocial variables. The most important prognostic factors are age and injury severity, which includes neurologic level, degree of injury completeness, and ventilator dependency.[5,12-16,20,22-25] Given comparable age and injury severity, females and whites have slightly higher survival rates than males and nonwhites, but the difference is not as great as it would be in the absence of SCI.[15]

Several types of psychosocial factors are also predictive of mortality. Early retrospective studies suggested that behavioral factors, such as alcohol abuse and poor self-care, were related to early mortality after SCI.[26,27] Later prospective studies identified relationships between a broad array of psychosocial variables and longevity; being generally more active, being employed, and adapting well after SCI were all related to a lower probability of mortality over the study periods.[28-32] The quality of long-term care received is also likely a strong predictor of mortality after SCI, although this factor has not generally been investigated.

Until recently, renal failure and other urinary tract complications were reported to be the leading causes of death among persons with SCI.[13,33-37] More recent studies suggest that respiratory complications, particularly pneumonia, have surpassed urinary tract complications as the leading underlying causes of both short- and long-term deaths of persons with tetraplegia.[8,9,23,38,39] The primary causes of death are different for persons with paraplegia, with septicemia, suicide, heart disease, and cancer now the leading causes.[8,16,25,38-42] Pulmonary embolism is also a leading cause of death after SCI, regardless of injury level.[38,39] It is noteworthy that multiple interrelated causes play a role in many deaths, and although urinary tract complications are no longer among the leading underlying causes of death, they may still be a secondary or contributing cause (eg, septicemia).[38,39]

This current study investigated patterns of mortality of individuals treated through the model SCI systems of care. Two sets of analyses were implemented, one relating to mortality during the first year after onset of SCI and the second for mortality patterns after the first year postinjury. Each set of analyses ascertained the trends in mortality rates and causes of death over time and prognostic factors for mortality. A sample life expectancy table was also created.

METHODS

The study population included 28,239 persons with traumatic SCI who were injured since 1973 and were seen within 1 year of injury at either a model SCI care system or a Shriner's Hospital SCI unit. All persons included in the study survived at least 24 hours after injury. Other eligibility criteria for inclusion in the *National Spinal Cord Injury Statistical Center* (NSCISC) database did not apply for this study.

Information that was extracted from the NSCISC database included age at injury, sex, race, etiology of injury, number of

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days from injury until model system admission, neurologic level of injury, Frankel grade[43] or, more recently, American Spinal Injury Association (ASIA) Impairment Scale,[44] ventilator-dependency, primary third-party sponsor of care, date of death or date last known to be alive, cause of death, and whether the cause of death was confirmed by autopsy. For non-NSCISC database cases, the information was collected using the same protocol and submitted separately to the NSCISC, except for sponsor of care, which was not collected for non-NSCISC database cases. For these purposes, ventilator-dependency was defined as requiring either partial or total respiratory support (including electrophrenic pacers) on a daily basis.

Follow-up information on the survival status of each person that was collected at each model system was supplemented by periodic searches of the Social Security Death Index that were most recently performed between August and December 1998. The Social Security files have been established to be 92.4% sensitive and 99.5% specific in identifying survival status for persons in the NSCISC database.[15] Cause of death information was obtained from a combination of hospital discharge summaries, death certificates, and autopsy reports.

Statistical Analysis

Descriptive statistics included frequencies and percentages. Calculation of percentages is based only on persons with known data under the assumption that missing data will be distributed in accordance with the known data.

Multiple logistic regression was used to assess the probability of mortality during the first year after injury among persons admitted to the model system within 24 hours of injury ($n = 9,805$).[45] To assess long-term survival, Cox proportional hazards regression analysis was performed beginning at the first anniversary of injury ($n = 21,433$).[46] Covariates included in both regression models were age at injury, gender, race (white vs all other), etiology of injury (violence vs all other), neurologic level of injury (C1-C4, C5-C8, T1-S5), Frankel grade or ASIA Impairment Scale (each grade separately), ventilator status (dependent vs independent), sponsor of care (each sponsor separately), injury year (1973-1977, 1978-1982, 1983-1987, 1988-1992, 1993-1998), and model system identification (each model system separately). All covariates were coded 0 if absent or 1 if present except age, which was used without modification.

Two statistical approaches were used to handle the occurrence of missing covariate information. First, separate indicator variables that were coded 1 if the data were missing and 0 otherwise were included in the model for each covariate. This approach permits all cases to be used, thereby enhancing precision with relatively unbiased results as long as the probability of data being missing is uncorrelated with either the value of the other covariates or mortality.[47] Separate analysis confirmed this condition to be true for this data set. Alternatively, a second analysis using only cases with complete data for all covariates was performed with virtually identical results but with somewhat less precision. Therefore, only results of the first analysis are reported.

Regression results are expressed as odds ratios or rate ratios and approximate 95% confidence limits. Confidence intervals that do not include the value of 1.0 imply a statistically significant difference in the odds of mortality for that category relative to the referent category at a two-tailed alpha of .05.

Actual numbers of deaths over time were determined using Cutler-Ederer life tables stratified by neurologic category and ventilator status.[48] Expected numbers of deaths in the absence of SCI were calculated based on life tables specific for age, gender, and race published by the federal government for the year 1985 (the approximate middle year of the study follow-up period)[49] and the exact length of follow-up of each person. A separate standardized mortality ratio was then calculated as the ratio of actual to expected deaths for each neurologic category and ventilator status from each of three starting points (time of injury, first anniversary of injury, and fifth anniversary of injury) until follow-up termination. These standardized mortality ratios were then applied to 1994 general population mortality rates (the most recent available)[50] to determine life expectancies.[51]

RESULTS

Sample Characteristics

The majority of study participants were males (81.1%). In terms of race/ethnicity, 67.6% were Caucasian, 20.7% were African American, 8.1% were Hispanic, and the remaining 3.6% were Asian, Native American, or other. Most injuries occurred between the ages of 16 and 30 years (54.1%), with the next highest percentage among those between 31 and 45 years (22.7%). Motor vehicle crashes were the most common etiology (43.3%), followed by acts of violence (18.8%), falls (18.5%), sporting injuries (11.3%), and other causes (8.1%). Fifty-three percent of all injuries were cervical, with C5-C8 injuries comprising 34.5% and C1-C4 injuries comprising 18.5% of the population. Similarly, 53.8% of all injuries were neurologically complete, with 27.2% motor functional (19% were either sensory sparing or motor nonfunctional). Only 2.9% were ventilator-dependent. Despite the broader eligibility and increased sample size for this study, these sample characteristics are virtually identical to the characteristics of the NSCISC database and registry.

Private insurance was the primary sponsor of care for 49.6% of the participants at discharge from inpatient rehabilitation, followed by Medicaid, which accounted for 24.1% of all cases. Workers' compensation accounted for 10.2% of the cases, with the remaining cases mostly accounted for by the Division of Vocational Rehabilitation (5.2%), Medicare (5%), and health maintenance organizations (HMOs) (3.6%). At the time of the most recent follow-up, 87.8% of participants were known to be alive.

First-Year Mortality Among Day 1 Admissions

Table 1 summarizes the odds ratios for survival through the first year postinjury for all day 1 admissions ($n = 9,805$). There is a consistent trend toward improving 1-year survival rates for persons admitted within 1 day of injury. The odds of dying for persons injured between 1993 and 1998 were only 33% as high as the odds of dying for persons injured between 1973 and 1977, a 67% reduction after adjusting for trends in age, sex, race, injury level, Frankel grade, ventilator status, etiology of injury, sponsor of care, and model system where treatment took place ($p < .05$).

Age, gender, injury level, Frankel grade, ventilator status, etiology of injury, and sponsor of care all had statistically significant associations with first-year mortality. Ventilator status was the strongest predictor, followed by age, Frankel grade, injury level, calendar year, sponsor, etiology, and gender. The odds of mortality were 39.5 times higher for ventilator-dependent persons, and the odds of mortality increased 1.07 times (7%) for each additional year of age at time of injury. In terms of Frankel grade, participants with complete injuries had 6.46 times greater odds of mortality than those who had incomplete motor-functional injuries. Although of a lesser magnitude, persons with motor-nonfunctional and sensory-only

Table 1: Logistic Regression Results for Mortality Among Day 1 Admissions During the First Year

Characteristic	OR*	95% CI
Injury Year		
1973-77	1.00	
1978-82	0.86	0.56-1.32
1983-87	0.60	0.39-0.93
1988-92	0.39	0.24-0.62
1993-98	0.33	0.20-0.53
Age (each year increase)	1.07	1.06-1.07
Gender		
Female	1.00	
Male	1.42	1.06-1.91
Race		
White	1.00	
Nonwhite	1.04	0.80-1.34
Injury Level		
T1-S5	1.00	
C5-C8	2.30	1.72-3.09
C1-C4	3.27	2.40-4.44
Unknown Level	11.60	5.54-24.40
Frankel Grade		
Motor Functional	1.00	
Motor Nonfunctional	3.22	2.09-4.94
Sensory Only	4.50	2.82-7.19
Complete	6.46	4.60-9.08
Unknown Grade	2.61	1.45-4.72
Ventilator Status		
Independent	1.00	
Dependent	39.50	26.90-57.90
Unknown Status	0.47	0.28-0.77
Etiology of Injury		
Nonviolence	1.00	
Violence	1.53	1.09-2.15
Unknown Etiology	0.74	0.40-1.39
Sponsor of Care		
All others	1.00	
Medicare	2.31	1.56-3.43
Medicaid	1.47	1.04-2.09
HMO	0.34	0.13-0.93
Unknown Sponsor	3.84	2.60-5.69

Abbreviations: OR, odds ratio; CI, confidence interval.
* Adjusted for model system where treatment took place (results not shown).

incomplete injuries also had substantially greater odds of mortality than those who were motor-functional (odds ratios = 3.22 and 4.50, respectively). In comparison to persons with T1-S5 injuries, those with C5-C8 injuries had 2.30 times greater odds of first-year mortality and those with C1-C4 injuries had 3.27 times greater odds of mortality. Men were 1.42 times more likely to die during the first year in comparison with women, whereas those injured by violence had 1.53 times greater odds of first-year mortality than those not injured by violence. HMO patients did significantly better than persons with other sponsors of care during the first year if they arrived at the model system within 1 day of injury, whereas Medicare (odds ratio = 2.31) and Medicaid patients (odds ratio = 1.47) had significantly higher odds of mortality. Race was not a significant predictor of mortality during the first year, all other things in the model being equal.

Model system identification was included in the regression model to control for its possible confounding effects on the other predictive factors in the model. This was particularly necessary for an analysis of trends over time for several reasons. Model systems have entered and withdrawn from the program at various times, and even those that have remained throughout the history of the program contributed different proportions of cases to the database over time. Moreover, the survival experience of persons treated at each model system differs as a result of differing characteristics (other than those included in the model) of the persons they treat. However, in conformance with the policy of the model system program designed to avoid the possibility of misinterpretation and misuse of system-specific data, individual model system results are not shown.

Mortality Among Year 1 Survivors

Table 2 summarizes the mortality pattern among first-year survivors. The results of the Cox model suggest that there was a significant trend toward improved survival rates after the first postinjury year between 1983 and 1992, but that this trend changed between 1993 and 1998. The mortality rate among persons injured between 1993 and 1998 was 33% higher than

Table 2: Proportional Hazards Regression Results of Mortality Among All Persons Beginning at 1 Year After Injury

Characteristic	Relative Risk*	95% CI
Injury Year		
1973-1977	1.00	
1978-1982	1.00	0.89-1.11
1983-1987	0.91	0.79-1.04
1988-1992	0.81	0.69-0.96
1993-1998	1.08	0.86-1.36
Age (each year increase)	1.06	1.06-1.06
Gender		
Female	1.00	
Male	1.26	1.13-1.40
Race		
White	1.00	
Nonwhite	0.97	0.88-1.07
Injury Level		
T1-S5	1.00	
C5-C8	1.40	1.27-1.54
C1-C4	2.01	1.79-2.24
Unknown Level	1.34	0.67-2.68
Frankel Grade		
Motor Functional	1.00	
Motor Nonfunctional	1.54	1.33-1.78
Sensory Only	1.96	1.69-2.27
Complete	2.16	1.94-2.41
Unknown Grade	1.03	0.76-1.40
Ventilator Status		
Independent	1.00	
Dependent	2.61	2.07-3.28
Unknown Status	1.18	0.95-1.47
Etiology of Injury		
Nonviolence	1.00	
Violence	1.15	1.01-1.32
Unknown Etiology	0.87	0.69-1.10
Sponsor of Care		
All others	1.00	
Medicare	1.60	1.34-1.90
Medicaid	1.56	1.36-1.79
HMO	1.55	0.99-2.42
Unknown Sponsor	1.12	0.97-1.31

Abbreviation: CI, confidence interval.
* Adjusted for model system where treatment took place (results not shown).

the mortality rate for persons injured between 1988 and 1992 (1.08/0.81 ($p < .05$), and 8% higher than for persons injured between 1973 and 1978 ($p > .05$). Because of the potential importance of this finding, a supplemental analysis was run without controlling for changing patterns of sponsors of care. Excluding sponsor of care weakened the trend toward improving mortality rates throughout all time periods, yet the jump after 1992 (34%, 1.17/0.87) remained unchanged (ie, changes in the percentage of cases having each sponsor of care over time did not explain the increased mortality that occurred in the latest time period).

Age at injury, gender, injury level, Frankel grade, ventilator status, etiology of injury, and sponsor of care were all significantly associated with survival rates after the first post-injury year ($p < .05$). Persons with HMO sponsorship had a survival rate as poor as those for persons with Medicare or Medicaid sponsorship after the first postinjury year, despite having a better survival rate during the first postinjury year. Race was not significantly associated with survival rates after the first postinjury year ($p > .05$).

Life Expectancy by Neurologic Impairment

Table 3 summarizes the life expectancy of an individual injured at age 20, with separate estimates provided for individuals with the following types of injuries: (1) Frankel grade D injuries; (2) T1-S5 (Frankel A-C); (3) C5-C8 (Frankel A-C); (4) C1-C4 (Frankel A-C); and (5) ventilator-dependent. Life expectancy for "no SCI" is based on the 1994 US federal government life table for all persons combined (not adjusted for race or gender). The standardized mortality ratios used to estimate life expectancies for each group at age 20 were 1.72, 2.82, 4.46, 7.12, and 34.60, respectively. Life expectancy estimates were then recalculated for persons who survive their first year (to age 21) and for those who survive their first 5 years (to age 25). Standardized mortality ratios for first-year survivors at age 21 were reduced slightly to 1.59, 2.58, 3.84, 5.46, and 12.20, respectively. Further declines in standardized mortality ratios were found for those who survived the first 5 years after injury, with values for these latter individuals at age 25 being 1.54, 2.36, 3.38, 5.05, and 7.50, respectively.

In the absence of SCI, life expectancy at age 21 should be reduced by 0.9 years relative to age 20 (table 3). Instead, because the standardized mortality ratio is slightly lower, there is no change in life expectancy for persons with Frankel grade D injuries, a gain of 0.2 years for persons with paraplegia, a gain of 1.0 years for persons with low-level tetraplegia, a gain of 2.4 years for persons with high-level tetraplegia, and a gain of 10.6 years for persons who are ventilator-dependent at discharge from inpatient rehabilitation. Persons without SCI who are still alive at age 25 should have a life expectancy that is 3.8 years lower than at age 21 (table 3). Instead, for persons with a Frankel grade D injury, life expectancy at age 25 (4 years later and 5 years after injury) is reduced by only 3.3 years (a theoretical gain of 0.5 years). As severity of injury increases, the theoretical gain in life expectancy for persons who survive at least 5 years after injury increases slightly, reaching 1.5 years for persons with high-level tetraplegia (a reduction of only 2.3 years rather than 3.8 years), and 6.4 years among ventilator-dependent persons (a gain of 2.6 years rather than a loss of 3.8 years).

As time postinjury increases, gains in life expectancy will be lower with advancing age at time of injury because the reduced standardized mortality ratios will have less time to have an effect. Other than the ventilator-dependent group, for which the standardized mortality ratio continued to decline rather substantially, there is little difference between calculated life expectancy at 5 years after injury and projections for life expectancy at 5 years after injury that would be obtained based on life expectancy at 1 year after injury.

Table 3: Life Expectancy (Years) by Neurological Impairment – Age at Injury = 20

Current Age	No SCI	Frankel D	Frankel Grade A, B, or C T1-S5	C5-C8	C1-C4	Ventilator Dependent
20	56.8	50.1	44.1	38.5	32.9	15.3
21	55.9	50.1	44.3	39.5	35.3	25.9
25	52.1	46.8	41.8	37.6	33.0	28.5

Table 4: Cause of Death (%) During the First Year After Injury by Year of Death

Cause of Death	Year of Death 1973-77 (n = 52)	1978-82 (n = 124)	1983-87 (n = 115)	1988-92 (n = 105)	1993-98 (n = 100)	Total (n = 496)
Respiratory	28.8	31.5	20.9	31.4	28.0	28.0
Heart	15.4	16.9	28.7	19.0	32.0	23.0
Pulmonary embolus	5.8	9.7	13.0	15.2	2.0	9.7
Ill-defined	17.3	8.1	7.8	9.5	5.0	8.7
Septicemia	5.8	10.5	7.0	4.8	8.0	7.5
Digestive	9.6	2.4	3.5	4.8	7.0	4.8
Urinary	5.8	4.0	2.6	3.8	4.0	3.8
External	1.9	4.0	2.6	4.8	4.0	3.6
Stroke	3.8	4.8	1.7	2.9	3.0	3.2
Nervous	1.9	3.2	4.3	1.0	3.0	2.8
Arteries	1.9	1.6	3.5	0.0	2.0	1.8
Cancer	0.0	1.6	2.6	1.0	1.0	1.4
All other	2.0	1.7	1.8	1.8	1.0	1.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

Causes of Death During the First-Year Postinjury

Table 4 summarizes the causes of death in the first year postinjury during each of five separate 5-year intervals, the most recent of which is 1993-1998. Because these are proportional data, trends in the distribution of deaths do not necessarily imply comparable trends in underlying mortality rates (ie, an increase in the percentage of a particular cause of death could be because that particular cause is increasing in frequency, or it may be remaining constant while other causes are decreasing in frequency).

Across all five time periods, respiratory and heart-related causes together accounted for more than half of all deaths (respiratory = 28%, heart = 23%). Only three other causes accounted for more than 5% of all deaths: pulmonary embolus (9.7%), ill defined conditions (8.7%), and septicemia (7.5%). In the most recent time period (1993-1998), 60% of all deaths were from either respiratory causes (28%) or heart-related causes (32%). There were fluctuations in the percentage of deaths due to particular conditions over the five time periods, although there were few consistent patterns of increases and declines. In fact, the overall χ^2 with unknowns removed is not significant, indicating no association between year of death and cause of death ($p > .05$).

Causes of Death After the First Year Postinjury

Unlike the causes of death within the first year postinjury, no single cause of death accounted for 20% of later deaths across the 25 years of study (table 5). The three primary causes of death were heart disease (18.8%), external causes (18.3%), and

Table 5: Cause of Death (%) Beyond the First Year After Injury by Year of Death

Cause of Death	1973-77 (n = 74)	1978-82 (n = 278)	1983-87 (n = 370)	1988-92 (n = 340)	1993-98 (n = 481)	Total (n = 1,543)
Heart	10.8	15.8	20.3	18.5	20.6	18.8
External	17.6	21.9	18.4	18.8	16.0	18.3
Respiratory	25.7	17.3	15.7	13.8	22.0	18.0
Septicemia	10.8	9.7	11.6	8.8	9.8	10.0
Cancer	5.4	8.6	5.9	11.5	11.9	9.5
Digestive	5.4	5.0	6.8	6.5	3.7	5.4
Ill-defined	8.1	6.5	3.8	2.6	3.5	4.1
Urinary	6.8	3.2	5.4	5.0	2.3	4.0
Stroke	1.4	4.0	3.5	3.8	2.9	3.4
Pulmonary embolus	5.4	4.3	2.2	4.7	1.9	3.2
Arteries	0.0	1.1	2.2	1.8	1.2	1.5
Nervous	0.0	1.1	0.8	0.9	2.3	1.3
All other	2.6	1.5	3.3	3.3	1.9	2.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

respiratory complications (18.0%). Septicemia and cancer each accounted for about 10% of all deaths. In the most recent study period (1993-1998), respiratory complications were the leading cause of death (22%), followed by heart disease (20.6%) and external causes (16.0%).

The overall χ^2 with unknowns removed was significant ($p = .0031$), suggesting a significant univariate association between year of death and cause of death. Subsequent logistic regression analyses (each cause against all others) adjusting for age at time of death, race, injury level, Frankel grade, ventilator status, etiology of injury, and length of survival postinjury revealed no significant time trends with the exception of deaths from urinary causes (table 6). There was a significant decrease in deaths from urinary causes only in the most recent time period ($p < .05$).

DISCUSSION

Information about mortality and life expectancy after SCI is important not only to those who have been injured, but also to the clinicians who care for them, payers who fund their care, and attorneys and life care planners who must develop estimates of damages and lifetime costs of care. Several authors have commented on the significant increase in survival of the SCI population since the development of modern systems of care during World War II.[2-5,13-15,52,53] Previous reports from the SCI Model Systems utilizing the NSCISC database have shown progressive improvement in mortality and life expectancy of SCI subjects since the program's inception in 1972.[14,15,21] The data presented here represent an update of NSCISC statistics, with an additional 5 years of patient enrollment and long-term follow-up permitting a fresh look at mortality outcomes in a changing healthcare environment.

Since the risk of medical and surgical complications resulting from acute catastrophic trauma is highest in the early postinjury period, it was expected that mortality would be higher in the first year and decrease to a lower level thereafter. For this reason, information for the first year postinjury and for subsequent follow-up was analyzed separately. These data showed an improvement in first year mortality during 1993-1998 when compared with the earlier reporting period, sustaining a pattern of progressively diminishing rates with each successive reporting period over the past 25 years. The proportional decrease in first-year mortality rate when comparing 1993-1998 with 1988-1992, however, was not as great as either of the two previous 5-year comparisons, indicating that there may be a "leveling off" of the improvement trend.

This point was underscored by the data on mortality after the first postinjury year, which showed a reversal of the previous trend of diminishing mortality rates. In fact, the rates for post-1-year follow-up subjects in 1993-1998 were not significantly different from those measured in 1973-1977 and were significantly increased (1.08/0.81 or 33%, [$p < .05$]) when compared with the 1988-1992 period. Subsequent analysis using both Cox models with truncated follow-up and person-year approaches revealed that the increase in mortality rates in the latest time period was concentrated mostly in the second postinjury year and, to a lesser extent, in postinjury years 3 to 5. Current annual mortality rates for persons who were 10 to 20 years postinjury actually continued to decline slightly.

This disturbing trend reversal in mortality in postinjury years 2 to 5 cannot be explained by statistical modeling that takes into account the sponsor of care. When separate models with and without sponsor of care were developed, the inclusion of sponsor of care reduced relative risks in all time periods but did not affect the trend reversal in the latest time period. Including sponsor of care in the model, however, does not control for the effects of any possible changes in policies or reimbursement practices that have occurred within each sponsor over time, such as the demand for shorter inpatient rehabilitation lengths of stay. Moreover, a large percentage of unknowns in the sponsor of care classification (36%) prevents any firm conclusions. Indeed, there is no obvious explanation for this trend reversal, which should prompt renewed efforts to investigate

Table 6: Logistic Regression Odds Ratios for Each Cause of Death Occurring After the First Postinjury Year Relative to All Other Causes for Each Time Period Relative to 1973-1977

Cause of Death	1978-1982 OR	1978-1982 95% CI	1983-1987 OR	1983-1987 95% CI	1988-1992 OR	1988-1992 95% CI	1993-1998 OR	1993-1998 95% CI
Respiratory	0.63	0.34-1.19	0.56	0.30-1.05	0.54	0.28-1.05	0.95	0.49-1.84
Heart, Stroke, and Arteries	1.62	0.74-3.55	1.86	0.86-4.05	1.35	0.61-2.99	1.37	0.61-3.07
External	1.42	0.68-2.96	1.53	0.74-3.17	1.78	0.83-3.83	1.76	0.80-3.87
Septicemia	1.16	0.49-2.76	1.37	0.58-3.21	1.12	0.45-2.75	1.28	0.52-3.17
Cancer	1.29	0.42-3.94	0.75	0.24-2.36	1.28	0.41-4.01	1.11	0.34-3.56
Urinary	0.43	0.14-1.36	0.62	0.21-1.81	0.50	0.16-1.63	0.16	0.04-0.64
Pulmonary Embolus	0.99	0.30-3.23	0.63	0.18-2.27	2.04	0.59-7.05	0.99	0.26-3.74
Digestive	0.76	0.24-2.42	0.93	0.30-2.85	0.75	0.23-2.47	0.32	0.09-1.18
Ill-defined	0.93	0.34-2.53	0.49	0.17-1.42	0.40	0.12-1.31	0.46	0.14-1.47

Odds ratios are adjusted for age, race, neurologic level of injury, Frankel grade, and ventilator status.
Abbreviations: OR, odds ratios; CI, confidence intervals.

the underlying causes of morbidity and mortality in SCI, with the goal of improved prevention and treatment.

Analysis of specific subject characteristics shows that ventilator status is the single strongest predictor of mortality in the first year, with ventilator-dependent subjects being 39.5 times more likely to die during the first year than those not requiring ventilator support. Although mortality rates decrease significantly after the first year, ventilator dependence continues to be associated with the highest relative risk in the follow-up years. The improving mortality rate in ventilator-dependent subjects after the first year is also reflected in the life expectancy projections that have been made using NSCISC data.[54] The data presented in this study also show significant increases in expected additional years of life for ventilator-dependent subjects who survive the first year and further increases for those surviving at year 5.

Not surprisingly, the degree of neurologic impairment, as measured by both Frankel Grade or ASIA Impairment Scale (completeness) and level of injury, was significantly correlated with mortality risk in the first year and subsequent follow-up years. These results confirm the findings of previous reports from spinal injury centers as well as from prior analyses of NSCISC data.[21,52,53] In general, the greater the degree of neurologic impairment, the higher the risk. Combining the contributions of injury level and completeness as a measure of impairment to predict mortality risk has been proposed as a more effective way to promote homogeneity of risk within impairment groupings.[55] In the present study, persons who lack motor-useful sparing below their level of injury (Frankel or ASIA grades A, B, and C) are stratified by high tetraplegia (C1-C4), low tetraplegia (C5-C8), and paraplegia (T1-S5). In addition, all persons with motor useful sparing (Frankel or ASIA grade D) are in a fourth group. While this scheme is slightly different than that proposed by Coll and colleagues[55] it is consistent with previous NSCISC studies.[21]

There has been widespread concern about the influence of managed care on quality in our health care system. Several authors have critiqued the introduction of managed care concepts in the care of persons with SCI and have noted that while there are potential cost savings in the short and long term, there is also risk of undertreating this vulnerable patient population.[56-58] In the most recent data collection period of 1993-1998, managed care has become increasingly prevalent, reaching 9.7% of model system cases (up from 1.7% from 1983-1987). Moreover, it is likely that more than 9.7% of persons with SCI currently have some form of managed care sponsorship since some persons who would otherwise be treated at model systems are treated elsewhere because of managed care contracts. At the same time, widespread reforms, including the introduction of managed care, have been undertaken in the government-funded programs of Medicare and Medicaid.[59,60]

For these reasons, we attempted to determine if there was a relation between the sponsor of care and mortality in this SCI population. In slightly more than one third of the subjects, the sponsor of care was unknown, somewhat diminishing the strength of any conclusions by requiring an assumption that the unknown sponsors are distributed in identical proportion to the known sponsors of care. Note that the sponsor of care is the primary payer and many subjects have multiple payers, particularly in the first year when an auto policy may yield to a health policy that may later yield to Medicaid or Medicare.

Medicare, which sponsors care for the elderly and previously disabled, was associated with the highest mortality risk in the first year, followed by Medicaid, which sponsors care for the disabled poor. Interestingly, subjects who had an HMO as the primary sponsor of care had a substantially lower mortality risk in the first year, but their risk after the first year increases to about the same level as that associated with Medicaid and Medicare. Although these data suggest that HMO-sponsored patients receive better care in the first year after SCI, it is also plausible that a selection bias favors HMO sponsorship. It has been alleged that HMO plans preferentially attract a population of the young, healthy, and employed who might be less likely to have the medical and socioeconomic mortality risk factors that are more common in the Medicare and Medicaid beneficiaries.[61,62] These individuals might also be attracted to lower HMO premiums compared with other private health insurance alternatives and not be as concerned about managed care restrictions as older, less healthy individuals. More concerning is the reversal of first-year mortality risk advantage in the HMO subjects who are at greater risk after the first year than their other non–government-funded counterparts. These data raise questions rather than suggest answers. Clearly, additional research is needed on this important and timely subject.

The "epidemic of violence" in the United States has been the subject of much discussion in the last decade.[63,64] Zafonte and Dijkers[65] have previously reported on Model SCI System data that showed that violence as the etiology of SCI has increased from 13.8% of all injuries in the period 1972-1977 to 23.8% in 1993-1997, with more than half of this having occurred in the past 10 years.[65] Further analysis of these data revealed that victims of violent SCI were younger, more often Hispanic or African American, male, less educated, and more likely to be unemployed than their nonviolent-injury counterparts. The violent etiology group was also more likely to develop serious pressure ulcers and was found to be more handicapped as measured by the Craig Handicap Assessment and Reporting Technique. Other authors have also commented on the potential for violent SCI etiology to be associated with increased morbidity and mortality risk.[66] In the data we present, violence-caused SCI was a significant predictor of first-year mortality and, to a lesser but still important degree, mortality thereafter. The tragedy of violence is thus compounded, with the consequence of added posttraumatic mortality risk. Additional research is needed to determine the factors that contributed to this increased risk so that prevention and treatment efforts can be improved.

In the last 15 years, much emphasis has been placed on the study of aging in persons with SCI, most of whom are injured at a young age. Relatively less attention has been given to the consequences of SCI in the elderly. Recent reports have shown that outcomes may be compromised in elderly persons who sustain SCI compared with younger individuals.[67] This study found that older age at the time of injury has a significant association with mortality risk, confirming the findings of previous studies.[21] The added risk associated with each year of additional age (6%) has not changed since the last model systems report that included data from 1973 to 1992.

Detailed life expectancy tables have been produced periodically using data from the NSCISC.[21] They have shown an improving but still diminished life expectancy for all categories of SCI, with greater neurologic impairment and greater age at injury being associated with the greatest proportional decrease in longevity. In this update of Model SCI System information, we were interested in determining whether the proportional reduction of life expectancy for persons with SCI improves significantly if they survive beyond the first year. Previous tables projected life expectancy for persons who survived at least 24 hours and made separate projections for those who survived at least 1 year. Since mortality rates decrease significantly during the first year, we questioned whether further improvement in mortality beyond the first year might result in a revision in life expectancy calculated at 5 years of survival. The data are presented for only one age at injury (20 years) as an example. As noted previously, the neurologic impairment groupings are: high and low tetraplegia without functional motor sparing, paraplegia without functional motor sparing, and all levels with functional motor sparing. In addition, ventilator-dependent subjects were grouped separately for analysis. The ventilator-dependent subjects were the only group to show actual gains in life expectancy between the first and fifth years. The non–ventilator-dependent groups showed no change in the proportional loss of life expectancy, indicating that the existing tables based on 24-hour and 1-year survival are adequate for all but ventilator-dependent subjects.[21,68]

The distribution of the various causes of death has also changed since the inception of model systems of care for SCI. Fifty years ago, renal failure and other urinary tract complications were the leading causes of mortality.[33] The most recent extensive review of model system data showed that pneumonia and other respiratory complications had become the most prominent underlying cause of death, both in the first year and for long-term follow-up.[21] Ischemic and nonischemic heart disease combined to comprise the second leading cause of death in that report, followed by septicemia. Urinary disorders, including renal failure, now accounted for only a small portion of the underlying causes of death.

In the present update of the model system experience, the proportional underlying cause of death is tracked over five time periods dating back to 1973, both during the first year and beyond the first year postinjury. Of the total sample, respiratory conditions continue to represent the leading cause of death in the first year, but in the 25 years of data collection, heart disease has doubled its percentage contribution to early deaths and now ranks second. Over that same time period, pulmonary embolus has dropped from a prominent cause of early death to only 2% of the first-year mortality in the most recent period, suggesting either improved prevention and treatment of embolism or a diagnostic overlap with heart disease.

The data on deaths beyond the first year are most remarkable for the increase of the percentage contribution of respiratory conditions to death during the most recent period, accompanied by a continued decreasing trend for urinary causes. Trends in the risk of death from various causes were studied using logistic regression analysis. Death from urinary causes was the only category to show a significant decline in risk during the most recent period, and mortality risk from respiratory causes was the only group to show a significant increase. This information only underscores the suggestion that more attention should be paid to the prevention and treatment of respiratory complications in SCI. The last two data collection periods have also seen an increase in the percentage contribution of cancer, perhaps reflective of the overall aging of the study population and a relative decrease in the contribution by other causes.

Although it is not clear that SCI is associated with an overall increased risk of cancer, SCI individuals appear to have added risk for the development of bladder cancer.[69,70] These data reinforce the need to attend to cancer prevention and surveillance in this population.

External causes of death—suicides, homicides, and accidents—continue to play a prominent role in deaths beyond the first year, being the second leading contributor in the total sample and third in the most recent time period. The findings are consistent with previous model systems data, which showed that suicide was the second leading cause of death in the youngest age group and in persons with paraplegia.[21,42] Clinical interventions should also address these external causes, with particular attention given to prevention of suicide.

Additional research is needed to determine if the latest disturbing trend toward increasing mortality rates after the first postinjury year will continue. Since violent etiology of SCI was associated with poorer life expectancy, it is important to identify factors that may underlie this relationship, such as social support systems. It is also important to identify the types of behaviors that place individuals at greater or lesser risk for mortality, particularly in association with causes of death that may be related to poor self-care (septicemia), indirect self-destructive behaviors such as smoking (cardiovascular and respiratory disease), or direct self-destructive behaviors (suicide).

CONCLUSION

While first-year mortality has continued to decrease, the risk of death after the first year postinjury has increased in this reporting period. Despite the increased long-term annual mortality rate in the latest time period, however, overall prognosis remains good. More than 98% of persons with SCI continue to survive each year. Limited analysis of the sponsor of care did not provide an adequate explanation for the reversal of long-term mortality rates. Ventilator dependence was the strongest predictor of mortality in the first year, followed by age, Frankel grade, level of injury, calendar year, sponsor of care, violent etiology, and male gender. Mortality after the first year was most strongly associated with age at injury, followed by Frankel grade, level of injury, ventilator status, sponsor of care, male gender, year of injury, and violent etiology. With the exception of persons who are ventilator-dependent, life expectancy was not shown to improve between the first and fifth years postinjury. While great improvements in mortality and life expectancy have been achieved since the Model SCI Systems program began, the current data support the need for renewed efforts to improve the prevention and treatment of the complications of SCI.

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