Research Article

The association between the etiology of a spinal cord injury and time to mortality in the United States: A 44-year investigation

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Objective: To determine the association between spinal cord injury (SCI) etiology categories and mortality, and examine the association between etiology sub-categories and mortality.

Design: Prospective cohort study.

Setting: Model Systems and Shriners Hospital SCI units.

Participants: Data were analyzed from 42,627 cases in the SCI Model System Collaborative Survival Study Database from 1973 to 2017. Those with SCI etiologies categorized as vehicular, violent, sports, falls, pedestrian, and medical were included.

Interventions: Not applicable.

Outcome Measure: Time to mortality after SCI.

Results: Relative to the sports related etiology category, those with medical, pedestrian, violence, falls, and vehicular related SCIs had a 2.00 (95% confidence intervals (CIs): 1.79–2.24), 1.57 (CIs: 1.34–1.83), 1.54 (CIs: 1.41–1.68), 1.35 (CIs: 1.25–1.45), and 1.26 (CIs: 1.17–1.35) higher hazard for mortality, respectively. Persons with SCIs from automobile crashes had a 1.38 (CIs: 1.23–1.56) higher hazard for mortality, whereas those with SCIs from motorcycle crashes had a 1.21 (CIs: 1.04–1.39) higher hazard for mortality, relative to other etiologies within the vehicular category. Those with SCIs from diving had a 1.37 (CIs: 1.18–1.59) higher hazard for mortality relative to other etiologies within the sports category.

Conclusions: Injury etiology categories and certain sub-categories were associated with a higher risk for early mortality. Understanding how additional factors such as socioeconomic status, co-occurring injuries, medical co-morbidities, and environmental aspects interact with SCI etiologies may provide insights for how etiology of injury impacts survival. These findings may serve as a development for extending long-term life expectancy by informing SCI prevention programs and care post-injury.

Keywords: Death, Epidemiology, Preventive medicine, Public health, Rehabilitation

Introduction

Spinal cord injuries (SCIs) are a leading cause of permanent disability, affecting up to 500,000 people across the

world each year.^{1,2} Individuals living with SCIs often experience many negative health related outcomes and comorbid conditions that diminish overall health status,^{3–9} which in turn, increases the likelihood of premature mortality, especially for those with complete lesions and tetraplegia.² While respiratory and circulatory related causes of death remain common in persons with SCIs,¹⁰ trends in other causes of death

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have shifted. For example, mortality rates for cancer, stroke, and urinary diseases have decreased; whereas, deaths from endocrine, metabolic, and nervous system diseases have increased.¹¹ These shifts in the causes of mortality demonstrate the need to examine how different factors influence changes in health for persons with SCIs.

Although SCI prevention efforts have been expanded, the incidence of SCI has been estimated at 54 cases per million persons and the total number of cases from 1993 to 2012 has generally increased.^{12,13} Despite advances in rehabilitation medicine,¹⁴ extensions in long-term life expectancy have remained negligible in the SCI population since the 1970s.¹⁵ As trends in the causes of SCIs have shifted,¹² it remains unclear how each etiology differentially affects mortality. Understanding the association between etiology and mortality can help the treatment of SCIs and refine the focus of secondary prevention strategies based on risk. This can potentially impact the long-term mortality outcomes by etiology. For example, underlying factors related to certain SCI etiologies such as disparities in socioeconomic status, co-occurring injuries, medical co-morbidities, and secondary complications may potentiate the risk of premature death.

Healthy People 2020 is a public health program committed to preventing disease, disability, injury, and early mortality in the United States.¹⁶ As part of the Healthy People 2020 initiative, a 10% reduction in fatal and non-fatal SCIs has been targeted.¹⁷ Investigations into the exact circumstances surrounding how SCIs occur are needed for the development of targeted prevention strategies.¹⁸ Understanding these circumstances will not only help to inform SCI prevention programs that align with the Healthy People 2020 goals, but also provide more awareness for how etiology contributes to premature mortality. This may then help shape the role of SCIs in Healthy People 2030. Therefore, the purposes of this investigation were to determine the association between SCI etiology categories and time to mortality and examine the association between etiology sub-categories and time to mortality.

Methods

Study sample

The SCI Model System Collaborative Survival Study Database was used for this investigation. Since 1973, data have been collected on persons whose traumatic SCIs were treated at either a SCI Model System or Shriners Hospital. Although databases are independent from one another, most individuals included in the Survival Study Database were also enrolled in the

National SCI Statistical Center Database or National Shriners Hospital SCI Database. Eligibility criteria include having a traumatic SCI, being admitted to the SCI Model System unit within 1-year of injury, completing rehabilitation in the SCI Model System, recovering within 7 days without rehabilitation, expiring during a SCI Model System hospitalization, and residing within the geographical catchment area of the SCI Model System to ease follow-up.^{18,19} Details regarding the eligibility criteria are described elsewhere.^{18,19} Treating physicians confirmed eligibility for inclusion and 30 centers comprised the Survival Study Database. The Survival Study Database uses a prospective cohort study design. Informed consent was provided by those included in the database and Institutional Review Board approval was obtained from each participating center.

Measures

Outcome variable

The primary outcome for this investigation was time to mortality after SCI. Date of death was identified by centers during routine follow-ups and from searches of the Social Security Death Index, state vital statistics databases, model systems hospital records, and newspaper obituaries. If dates of death were not identified by these annual searches, individuals were assumed to be living and their date last known to be alive was typically documented as the first day in the new calendar year (approximately one month prior to the search to account for the lag time in reporting deaths). The use of the Social Security Death Index in identifying survival status for persons in the Survival Study Database has demonstrated 92.4% sensitivity and 99.5% specificity.²⁰ Exclusions occurred for about 10% of individuals who were eligible for the Survival Study Database but were not reported as dead from SCI Model Systems that lost funding and dropped out of the program.

Exposure variable

Etiology of the SCI was recorded by hospital admission records or from personal interviews and entered into the Survival Study Database. Those with an SCI etiology categorized as vehicular, violent, sports, falls, pedestrian, and medical as defined in the SCI Model Systems Data Dictionary were included.²¹

Investigators created *a priori* etiology sub-categories based on the relative frequency of each SCI etiology within the categories, wherein the most occurring etiologies in each category were compared to the other injury etiologies within the same category. Injuries from automobile crashes, motorcycle crashes, and all

other etiologies within the vehicular category were sub-categorized, while SCIs from gunshot wounds and all other etiologies within the violence category were sub-categorized. Persons with SCIs from diving and all other etiologies within the sports category were sub-categorized. Injuries from falls and being struck by an object served as sub-categories for the falls category because those are the only two etiologies within the falls category. No sub-categories could be created for the pedestrian and medical categories because there were no specific etiologies within those categories.

Covariates

Demographic and injury characteristics were collected using standard protocols by trained personnel or were obtained from admission records and interviews.^{19,22,23} Sex (male, female), ethnicity (African American, Caucasian, Hispanic, other (Native American, Eskimo, Aleutian; Asian or Pacific Islander; Some Other Race, Multiracial)), age at injury, and year of injury were included. Ventilation dependency was defined as any usage of a ventilator to sustain respiration at discharge. A physician or other trained staff member conducted examinations to determine the category of neurological impairment (complete paraplegia, incomplete paraplegia, complete tetraplegia, incomplete tetraplegia). Definitions for the level and severity of each category of neurological impairment are described elsewhere.²¹

Statistical analysis

A Kaplan–Meier estimator was used to determine the median age at death by SCI etiology category. A Cox proportional hazard regression model examined the association between each SCI etiology category and time to mortality after adjusting for the category of neurological impairment, sex, ethnicity, ventilator dependence, year of injury, and age at injury. Separate Kaplan–Meier estimators were used to determine the median age at death stratified by SCI etiology sub-categories. Cox models examined the associations between SCI etiology sub-categories and time to mortality, after adjusting for the same covariates.

To identify if missing data from our exposure variable biased the outcome, an additional Kaplan–Meier estimator was conducted to determine if there were meaningful differences in the age at mortality between those with and without etiology data. For each of the Cox models, data were left truncated because individuals entered the study at different ages. Thus, time was defined as the number of years since the SCI occurred, and age at injury was used as the entry variable to

account for this. Right censoring occurred if individuals were identified as alive in the database. All analyses were performed with SAS 9.4 software (SAS Institute; Cary, NC) and an alpha level of 0.05 was used for all analyses.

Results

Of the 53,544 cases in the dataset, exclusions occurred for unknown etiology ($n = 3045$), ventilator usage ($n = 2002$), sex ($n = 2$), ethnicity ($n = 3541$), category of neurological impairment ($n = 1279$), age ($n = 1$), and for having a minimal deficit category of neurological impairment ($n = 1047$). After exclusions, 42,627 (79.6%) cases remained and their descriptive characteristics are presented in Table 1. For those who died, the causes of death are shown in Table 2. Respiratory diseases were a common cause of death across etiology categories. The median age at death was 70 years (95% confidence intervals (CIs): 69, 71) for those with missing etiology and 71 years (CIs: 71, 72) for those with etiology data (Log-Rank $P = .03$; Wilcoxon $P = .18$), thereby suggesting missing etiology data may not be meaningful for influencing the outcome.

Supplementary Figure 1 provides the Kaplan–Meier curves for time to mortality stratified by SCI etiology category. The median age at death was 75 years (CIs: 74, 75) for fall related SCIs; 74 years (CIs: 73, 75) for medical related SCIs; 70 years (CIs: 69, 71) for vehicular related SCIs; 68 years (CIs: 66, 70) for sports related SCIs; 65 years (CIs: 64, 72) for pedestrian related SCIs; and 64 years (CIs: 63, 65) for violence related SCIs (Log-Rank $P < .01$; Wilcoxon $P < .01$). Results from the Cox model for the association between each SCI etiology category and time to mortality are presented in Table 3. Those with medical related SCIs had the highest hazard (hazard ratio (HR): 2.00; CIs: 1.79, 2.24; $P < .01$) for mortality across etiology categories compared to those in the sports category (reference group).

Kaplan–Meier curves for time to death stratified by SCI sub-categories within the vehicular and sports etiology categories are presented in Supplementary Figures 2 and 3, respectively. For the vehicular category, the median age at death for those with other, motorcycle crash, and automobile crash SCIs was 76 (CIs: 74, 79), 70 (CIs: 69, 72), and 69 (CIs: 69, 70) years, respectively (Log-Rank $P < .01$; Wilcoxon $P < .01$). Similarly, for the sports category, the median age at death for persons with other and diving SCIs was 73 (CIs: 71, 76) and 63 (CIs: 60, 64) years, respectively (Log-Rank $P < .01$; Wilcoxon $P < .01$). The results of each Cox model for the association between SCI etiology sub-categories and time to mortality are presented in Table 4. Both those with an injury from automobile (HR: 1.38;

Table 1 Descriptive characteristics of those included.

	Falls (n = 10,397)	Medical (n = 1329)	Pedestrian (n = 641)	Sports (n = 4752)	Vehicular (n = 19,271)	Violence (n = 6237)
Sex (n (%))						
Male	8558 (82.3%)	855 (64.3%)	457 (71.2%)	4181 (87.9%)	14,449 (74.9%)	5346 (85.7%)
Race/Ethnicity (n (%))						
Caucasian	7708 (74.1%)	1028 (77.3%)	402 (62.7%)	4197 (88.3%)	15,027 (78.0%)	1736 (27.8%)
African American	1784 (17.2%)	194 (14.6%)	165 (25.7%)	293 (6.2%)	2626 (13.6%)	3856 (61.8%)
Hispanic	577 (5.5%)	53 (4.0%)	41 (6.4%)	150 (3.2%)	924 (4.8%)	436 (7.0%)
Other	328 (3.2%)	54 (4.1%)	33 (5.2%)	112 (2.3%)	694 (3.6%)	209 (3.4%)
Category of Neurological Impairment (n (%))						
Incomplete Paraplegia	2134 (20.5%)	646 (48.6%)	143 (22.3%)	304 (6.4%)	3117 (16.2%)	1549 (24.8%)
Complete Paraplegia	2483 (23.9%)	306 (23.0%)	172 (26.8%)	357 (7.5%)	5446 (28.2%)	2759 (44.3%)
Incomplete Tetraplegia	4185 (40.3%)	308 (23.2%)	197 (30.8%)	2246 (47.3%)	6261 (32.5%)	857 (13.7%)
Complete Tetraplegia	1595 (15.3%)	69 (5.2%)	129 (20.1%)	1845 (38.8%)	4447 (23.1%)	1072 (17.2%)
Ventilator Dependency (n (%))	439 (4.2%)	33 (2.4%)	38 (5.9%)	179 (3.7%)	588 (3.0%)	176 (2.8%)
Dead (n (%))	3504 (33.7%)	569 (42.8%)	196 (30.5%)	988 (20.7%)	4930 (25.5%)	1609 (25.8%)
Age at Death (years)	64.0 (22.0)	68.0 (20.0)	51.0 (24.0)	45.0 (19.0)	52.0 (23.0)	45.0 (23.0)
Year of Death	2003 (14.0)	2003 (13.0)	2003 (15.0)	2004 (12.0)	2004 (13.0)	2003 (14.0)
Δ Death-Injury (years)	8.0 (15.0)	6.0 (10.0)	12.0 (17.0)	17.0 (19.0)	13.0 (17.0)	12.0 (16.0)
Age at Injury (n (%))						
Birth-15 years	201 (1.9%)	174 (13.1%)	78 (12.2%)	470 (9.9%)	1086 (5.7%)	337 (5.4%)
16-30 years	2630 (25.3%)	136 (10.2%)	236 (36.8%)	3108 (65.4%)	9875 (51.2%)	4005 (64.2%)
31-45 years	2637 (25.4%)	161 (12.1%)	182 (28.4%)	748 (15.7%)	4582 (23.8%)	1435 (23.0%)
46-60 years	2658 (25.6%)	400 (30.1%)	103 (16.1%)	322 (6.8%)	2545 (13.2%)	378 (6.1%)
≥61 years	2271 (21.8%)	458 (34.5%)	42 (6.5%)	104 (2.2%)	1183 (6.1%)	82 (1.3%)
Year of Injury (n (%))						
1979 and under	1051 (10.1%)	70 (5.3%)	82 (12.8%)	700 (14.7%)	2372 (12.3%)	609 (9.7%)
1980-1989	2225 (21.4%)	246 (18.5%)	172 (26.8%)	1331 (28.0%)	4628 (24.0%)	1495 (24.0%)
1990-1999	2345 (22.5%)	385 (29.0%)	165 (25.8%)	921 (19.4%)	4438 (23.0%)	2044 (32.8%)
2000-2009	2722 (26.2%)	379 (28.5%)	149 (23.2%)	1111 (23.4%)	5162 (26.8%)	1341 (21.5%)
2010 and over	2054 (19.8%)	249 (18.7%)	73 (11.4%)	689 (14.5%)	2671 (13.9%)	748 (12.0%)

Notes: Results are presented as median (interquartile range) or frequency (percentage) as indicated. Δ Death-Injury = difference between age at death and age at injury.

Table 2 The causes of death by etiology category.

	Falls	Medical	Pedestrian	Sports	Vehicular	Violence
Infectious and Parasitic Diseases	324 (9.7%)	49 (9.4%)	18 (9.6%)	109 (11.9%)	500 (10.8%)	208 (13.3%)
Cancer	346 (10.3%)	67 (12.9%)	13 (6.9%)	63 (6.9%)	353 (7.6%)	112 (7.2%)
Endocrine, Nutritional and Metabolic Diseases	79 (2.4%)	13 (2.6%)	8 (4.2%)	14 (1.5%)	101 (2.2%)	32 (2.1%)
Diseases of Blood and Blood-Forming Organs	13 (0.4%)	5 (1.0%)	0 (0.0%)	1 (0.1%)	8 (0.2%)	4 (0.3%)
Mental Disorders	30 (0.9%)	3 (0.6%)	4 (2.1%)	5 (0.5%)	38 (0.8%)	13 (0.8%)
Diseases of the Nervous System	55 (1.6%)	8 (1.5%)	1 (0.5%)	11 (1.2%)	82 (1.8%)	16 (1.0%)
Ischemic Heart Disease	395 (11.7%)	74 (14.3%)	15 (8.0%)	52 (5.7%)	344 (7.4%)	89 (5.7%)
Diseases of Pulmonary Circulation	91 (2.7%)	8 (1.5%)	4 (2.1%)	33 (3.6%)	137 (2.9%)	37 (2.4%)
Non-Ischemic Heart Disease	296 (8.8%)	36 (7.0%)	18 (9.6%)	43 (4.7%)	371 (8.0%)	103 (6.6%)
Cerebrovascular Disease	105 (3.1%)	26 (5.0%)	5 (2.7%)	33 (3.6%)	149 (3.2%)	35 (2.2%)
Diseases of Arteries	36 (1.1%)	37 (7.2%)	1 (0.5%)	3 (0.3%)	34 (0.7%)	10 (0.6%)
Diseases of Veins and Lymphatics	6 (0.2%)	0 (0.0%)	0 (0.0%)	1 (0.1%)	11 (0.2%)	3 (0.2%)
Respiratory Diseases	668 (19.9%)	84 (16.3%)	36 (19.2%)	209 (22.7%)	942 (20.3%)	206 (13.2%)
Diseases of the Digestive System	134 (4.0%)	21 (4.1%)	12 (6.4%)	33 (3.6%)	180 (3.9%)	65 (4.2%)
Diseases of the Urinary System	81 (2.4%)	21 (4.1%)	3 (1.6%)	11 (1.2%)	129 (2.8%)	47 (3.0%)
Diseases of the Musculoskeletal System	30 (0.9%)	6 (1.2%)	1 (0.5%)	6 (0.6%)	47 (1.0%)	19 (1.2%)
Congenital Anomalies	1 (0.1%)	3 (0.6%)	2 (1.1%)	0 (0.0%)	3 (0.1%)	6 (0.4%)
Symptoms and Ill-Defined Conditions	88 (2.6%)	8 (1.6%)	7 (3.7%)	33 (3.6%)	102 (2.2%)	67 (4.3%)
External Causes of Death	230 (6.8%)	16 (3.1%)	13 (6.9%)	149 (16.2%)	541 (11.7%)	242 (15.5%)
Unknown	350 (10.4%)	32 (6.2%)	27 (14.4%)	110 (12.0%)	565 (12.2%)	247 (15.8%)

Notes: There were 616 missing observations for the cause of death. All values are listed as frequency (percentage). Cause of death data differed from the overall death frequency by etiology category data used in the analyses.

Table 3 Results for the association between SCI etiology categories and time to mortality.

	Hazard Ratio	95% Confidence Interval
Falls (reference: Sports)	1.35*	1.25, 1.45
Medical (reference: Sports)	2.00*	1.79, 2.24
Pedestrian (reference: Sports)	1.57*	1.34, 1.83
Vehicular (reference: Sports)	1.26*	1.17, 1.35
Violence (reference: Sports)	1.54*	1.41, 1.68
Complete Paraplegia (reference: Incomplete Paraplegia)	1.44*	1.36, 1.53
Incomplete Tetraplegia (reference: Incomplete Paraplegia)	1.27*	1.20, 1.35
Complete Tetraplegia (reference: Incomplete Paraplegia)	2.60*	2.44, 2.77
Male (reference: Female)	1.24*	1.19, 1.30
Caucasian (reference: Other)	1.35*	1.21, 1.51
African American (reference: Other)	1.58*	1.40, 1.77
Hispanic (reference: Other)	1.36*	1.15, 1.60
Ventilator Dependence (reference: No Ventilator Dependency)	5.35*	4.97, 5.76
Year of Injury in 1980–1989 (reference: 1970–1979)	0.90*	0.85, 0.95
Year of Injury in 1990–1999 (reference: 1970–1979)	0.82*	0.77, 0.87
Year of Injury in 2000–2009 (reference: 1970–1979)	0.94	0.87, 1.00
Year of Injury in 2010 or over (reference: 1970–1979)	1.07	0.95, 1.21
Age at Injury between 16 and 30 years (reference: Birth-15 years)	1.07	0.95, 1.21
Age at Injury between 31 and 45 years (reference: Birth-15 years)	1.32*	1.16, 1.50
Age at Injury between 46 and 60 years (reference: Birth-15 years)	1.61*	1.40, 1.85
Age at Injury ≥61 years (reference: Birth-15 years)	2.28*	1.95, 2.66

*P < .05.

Note: Age at injury was the entry variable. There were 42,627 observations in the model. SCI, spinal cord injury.

CI: 1.23, 1.56; $P < .01$) and motorcycle crashes (HR: 1.21; CI: 1.04, 1.39; $P < .01$) had a higher hazard for mortality compared to other etiologies within the vehicular category. Similarly, those with injuries from diving (HR: 1.37; CI: 1.18, 1.59; $P < .01$) had a higher hazard for mortality compared to other etiologies within the sports category.

The mean and CIs for the descriptive characteristics and causes of death by etiology categories are in Supplementary Tables 1 and 2, respectively. Likewise, the Kaplan–Meier curves for time to mortality stratified by etiologies within the violent and falls categories are presented in Supplementary Figures 4 and 5, respectively. For the violent category, the median age at death for those with SCIs from gun shots was 63 years (CI: 62, 65) and other violence was 67 years (CI: 63, 70) (Log-Rank $P < .01$; Wilcoxon $P < .01$). Likewise, for the falls category, the median age at death for persons hit by an object and who fell was 70 (CI: 68, 72) and 75 years (CI: 75, 76), respectively (Log-Rank $P < .01$; Wilcoxon $P < .01$). The results of each Cox model for the association between SCI etiologies and mortality within the falls and violent categories are shown in Supplementary Table 3. There were no statistically significant associations for the etiologies within the falls and violent categories and time to mortality.

Discussion

The principal findings from this investigation revealed that each SCI etiology category was associated with a

higher risk for mortality when compared those in the sports category, and persons with medical related SCIs had the highest risk for mortality across all categories. Those with SCIs from automobile or motorcycle crashes had a higher risk for mortality compared to other etiologies within the vehicular category. Persons with SCIs from diving had a higher risk for mortality compared to other sports related injuries. Our findings suggest that healthcare providers and SCI prevention strategies should consider how each injury etiology effects mortality risk, and not just the number of cases by etiology of injury. These results also provide opportunities for the refinement of primary and secondary injury prevention strategies as outlined by Healthy People 2020 to reduce fatal and nonfatal SCIs by at least 10%.¹⁷ Advancing such prevention strategies may not only help reduce the incidence of SCIs and extend the long-term life expectancy of those sustaining this injury, but it may also improve quality of life and reduce medical costs.

The variation across hazard ratios for the association between SCI etiology categories and time to mortality suggests that other factors related to each etiology may have contributed to premature mortality. For example, although the overall incidence of a medical related SCI is lower than other etiology categories, medical related SCIs were associated with the highest risk for mortality. Medical related SCIs are most likely to occur during scoliosis correction and spinal stabilization procedures following neoplastic disease.²⁴ In such cases,

Table 4 Results for the association between SCI etiology sub-categories and time to mortality.

	Hazard Ratio	95% Confidence Interval
<i>Vehicular</i>		
Automobile (reference: Other)	1.38*	1.23, 1.56
Motorcycle (reference: Other)	1.21*	1.04, 1.39
Complete Paraplegia (reference: Incomplete Paraplegia)	1.55*	1.39, 1.72
Incomplete Tetraplegia (reference: Incomplete Paraplegia)	1.30*	1.17, 1.44
Complete Tetraplegia (reference: Incomplete Paraplegia)	2.85*	2.57, 3.15
Male (reference: Female)	1.41*	1.31, 1.51
Caucasian (reference: Other)	1.30*	1.11, 1.51
African American (reference: Other)	1.41*	1.19, 1.67
Hispanic (reference: Other)	1.44*	1.13, 1.84
Ventilator Dependence (reference: No Ventilator Dependency)	5.21*	4.62, 5.87
Year of Injury in 1980–1989 (reference: 1970–1979)	0.91*	0.84, 0.98
Year of Injury in 1990–1999 (reference: 1970–1979)	0.82*	0.75, 0.90
Year of Injury in 2000–2009 (reference: 1970–1979)	1.00	0.90, 1.11
Year of Injury in 2010 or over (reference: 1970–1979)	1.03	0.83, 1.30
Age at Injury between 16 and 30 years (reference: Birth–15 years)	0.96	0.79, 1.16
Age at Injury between 31 and 45 years (reference: Birth–15 years)	1.17	0.96, 1.44
Age at Injury between 46 and 60 years (reference: Birth–15 years)	1.38*	1.11, 1.71
Age at Injury ≥61 years (reference: Birth–15 years)	1.63*	1.27, 2.09
<i>Sports</i>		
Diving (reference: Other)	1.37*	1.18, 1.59
Complete Paraplegia (reference: Incomplete Paraplegia)	1.24	0.77, 2.00
Incomplete Tetraplegia (reference: Incomplete Paraplegia)	1.24	0.83, 1.84
Complete Tetraplegia (reference: Incomplete Paraplegia)	2.36*	1.59, 3.52
Male (reference: Female)	1.15	0.91, 1.46
Caucasian (reference: Other)	1.02	0.61, 1.71
African American (reference: Other)	1.24	0.70, 2.19
Hispanic (reference: Other)	1.87	0.89, 3.91
Ventilator Dependence (reference: No Ventilator Dependency)	5.14*	4.06, 6.50
Year of Injury in 1980–1989 (reference: 1970–1979)	0.81*	0.70, 0.95
Year of Injury in 1990–1999 (reference: 1970–1979)	0.79*	0.64, 0.96
Year of Injury in 2000–2009 (reference: 1970–1979)	0.95	0.72, 1.24
Year of Injury in 2010 or over (reference: 1970–1979)	1.34	0.80, 2.24
Age at Injury between 16 and 30 years (reference: Birth–15 years)	0.93	0.73, 1.18
Age at Injury between 31 and 45 years (reference: Birth–15 years)	1.23	0.92, 1.65
Age at Injury between 46 and 60 years (reference: Birth–15 years)	1.53*	1.03, 2.27
Age at Injury ≥61 years (reference: Birth–15 years)	1.15	0.63, 2.10

*P < .05.

Notes: Age at injury was the entry variable. There were 19,271 and 4752 observations for the vehicular and sports etiology categories, respectively. SCI, spinal cord injury.

multimorbid conditions, that are often linked to cancer, and decreased physical function prior to the SCI already independently contribute to reduced life expectancy for these individuals.²⁵ For example, our findings suggest that more individuals with a medical related SCIs died from cancer than persons with sports, vehicular, or violence related SCIs. Clinicians and public health advocacy groups should bolster the support of care for those with medical etiologies in order to improve the health and longevity of these patients. Persons sustaining pedestrian related SCIs may have had co-occurring injuries to the legs and pelvis,²⁶ but also severe injuries to the head that were life threatening.²⁷ Traumatic brain injuries can shorten longevity, even in those who sustain this injury for over a year.²⁸ These injuries may help to explain why those with pedestrian related SCIs had a higher risk for early mortality. Interventions for

lowering pedestrian collisions by reducing pedestrian mobile phone usage while in a crosswalk and illegal entry into an intersection by pedestrians and motorists may reduce the incidence and severity of pedestrian injuries.²⁹

Although motor vehicle crashes are a leading cause of SCI, they also typically result in concomitant injuries to various sites in the body (e.g. extremities, head, organs), thereby increasing the risk of morbidity and death.^{30–32} Similar to those with pedestrian related SCIs, head injuries are a common co-occurring injury for persons sustaining vehicular related SCIs.³³ However, vehicular related brain injuries tend to be mild in severity,³⁴ which may explain why persons with vehicular related SCIs had a lower risk for mortality compared to the other etiologies. Public health strategies to continue improving safety in motor vehicles such as embracing

smart cars and autonomous vehicles may further mitigate the incidence of SCIs and severity of co-occurring injuries.³⁵ Similarly, multicomponent interventions that include sobriety checkpoints, public education campaigns, and media advocacy efforts to reduce alcohol impaired driving may reduce the incidence and severity of vehicular crashes.³⁶

These factors may also explain the differences in risks for the association between SCI etiology sub-categories within the vehicular category and mortality. While motorcyclists are less protected and more susceptible to high speed collisions than automobilists, persons with SCIs from motorcycle crashes may not have had simultaneous injuries that were life threatening because most motorcycle crash injuries occur at the lower and upper extremities.^{37,38} Likewise, persons that sustained SCIs from automobile crashes may have also been at a greater risk for life threatening injuries to the thoracoabdominal region such as rib fractures, splenic trauma, and hepatic injuries.^{32,39} These types of concomitant injuries may have long-term implications on the longevity of those that sustain a SCI. For example, splenic dysfunction is common in those with SCIs and contributes largely to immune suppression. Impairments in immunity may lead to infections of the respiratory and urinary systems, which are common causes of death in persons with SCIs.^{11,40} Moreover, systemic inflammation that occurs after SCI is linked to organ dysfunction, thereby also contributing to premature mortality.⁴⁰

Sport related SCIs occur in a variety of individual and team sports, with the majority of cases occurring in younger males.^{41,42} The high numbers of young, healthy individuals who participate in sports may explain why those with sports related SCIs had the lowest risk for mortality across etiology categories. The finding that persons with SCIs from diving had a higher risk for mortality compared to other sports related SCIs, even after controlling for relevant covariates (e.g. category of neurological impairment, ventilator dependence), warrants further investigation, especially considering that serious concomitant injuries present in those with SCIs from diving are rare.^{43,44} Persons with SCIs from diving may have had particular difficulty with morbidities and reintegrating back in the community because their level and severity of the injury is often high. Other risk factors for mortality such as poor life satisfaction, physical independence, and mobility may be prevalent for those with injuries from diving or other sports because they were likely active pre-injury. This may explain why more persons with sports related SCIs died from external causes (including suicide) than

those with falls, medical, vehicular, or pedestrian related SCIs.

Violence related SCIs tend to be prevalent among young, ethnically diverse males who are not married and are unemployed.^{45,46} These individuals are also more likely to experience post-traumatic stress disorder than those with other SCI etiologies, placing them at a higher risk for substance abuse and behavioral problems.⁴⁷ This aligns with our findings that indicate more individuals with violence related SCIs died from external causes such as suicide than those with vehicular, falls, medical, and pedestrian related SCIs. The sociodemographic characteristics of persons with violence related SCIs suggest they may have poor health insurance, thereby placing them at higher likelihood for rehospitalizations and other negative health outcomes.^{48,49} These factors may explain why persons sustaining violence related SCIs had a higher risk for mortality in our analyses. Secondary prevention programs targeting the treatment of post-traumatic stress disorder may reduce behavioral related risk factors that accelerate mortality. Similarly, bridging the gap for equitable access of health care to consumers of lower socioeconomic status may help extend life expectancy post-SCI.

In contrast to those with violence related SCIs, fall related SCIs tend to be more prevalent in older adults and the incidence of fall related SCIs is rising because the older adult population is growing.¹² Although persons that have incomplete lesions to the spinal cord after falling often regain some physical function,⁵⁰ the heightened risk of reoccurring falls and subsequent fractures may increase the risk of mortality for those sustaining fall related SCIs.⁵¹ To prevent reoccurring falls and subsequent injuries, risk factors such as environmental barriers for being fully ambulatory, exercise and dietary supplementation, a person's sensory (e.g. vision, balance, and mobility), and pain medications should be evaluated.⁵²

Some limitations should be noted. The dataset had a large amount of missing data for certain socioeconomic (e.g. family income level, primary payer) and health related variables (e.g. diabetes diagnosis, smoking status, self-perceived health status) that may have affected mortality but could not be accounted for in this analysis. There was also a large amount of missing data for the variables included in analyses (20.4%); however, missingness for our exposure variable (etiology) was not meaningful in influencing age at death (1-year). Other factors that may have contributed to premature mortality such as co-occurring injuries and quality of health care were not available. Future

investigations should evaluate how the relationship between injury etiology and concomitant injuries influence longevity in persons with SCIs. Those individuals with severe, life threatening SCIs at time of injury were not included in the database as per the inclusion criteria. The Kaplan–Meier estimators may have been influenced by the entry variable (age at injury) rather than differential survival; therefore, those results should be interpreted with some caution.

Conclusions

The etiology of a SCI was associated with differential time to mortality. Attention should be given to the risk of mortality specific to each SCI etiology and not just the number of cases by injury etiology. These results can inform injury prevention strategies aiming to reduce fatal and nonfatal SCIs such as those outlined in Healthy People 2020, and also post-SCI risk factors that compromise longevity. Likewise, our results can inform future goals for reducing fatal and nonfatal SCIs in Healthy People 2030. A better understanding of how additional factors such as socioeconomic status, co-occurring injuries, medical co-morbidities, environmental aspects, and how these factors may interact with SCI etiology can provide insights for how the etiology of injury impacts survival. Moreover, this knowledge can refine the design of future primary and secondary SCI prevention programs. Such refinement to SCI prevention programs may serve as a needed development for extending long-term post-SCI life expectancy.

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