ORIGINAL ARTICLE

Trends in Life Expectancy After Spinal Cord Injury

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ABSTRACT. Strauss DJ, DeVivo MJ, Paculdo DR, Shavelle RM. Trends in life expectancy after spinal cord injury. Arch Phys Med Rehabil 2006;87:1079-85.

Objective: To investigate whether there have been improvements in survival after spinal cord injury (SCI) over time, both in the critical first 2 years after injury and in the longer term.

Design: Pooled repeated observations analysis of person-years. For each person-year, the outcome variable is survival and mortality, and the explanatory variables include age, level and grade of injury, and calendar year (the main focus of the analyses). The method can be viewed as a generalization of proportional hazards regression.

Setting: Model spinal cord injury systems and hospital SCI units across the United States.

Participants: Persons (N=30,822) admitted to a Spinal Cord Injury Model Systems facility a minimum of 1 day after injury. Only persons over 10 years of age and known not to be ventilator dependent were included. These persons contributed 323,618 person-years of data, with 4980 deaths, over the 1973 to 2004 study period.

Interventions: Not applicable.

Main Outcome Measure: Survival.

Results: Other factors being equal, over the last 3 decades there has been a 40% decline in mortality during the critical first 2 years after injury. However, the decline in mortality over time in the post–2-year period is small and not statistically significant.

Conclusions: The absence of a substantial decline in mortality after the first 2 years postinjury is contrary to widely held impressions. Nevertheless, the finding is based on a large database and sensitive analytic methods and is consistent with previous research. Improvements in critical care medicine after spinal cord injury may explain the marked decline in short-term mortality. In contrast, although there have no doubt been improvements in long-term rehabilitative care, their effect in enhancing the life span of persons with SCI appears to have been overstated.

Key Words: Epidemiology; Life expectancy; Mortality; Rehabilitation; Spinal cord injuries; Survival.

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Supported in part by the National Institute on Disability and Rehabilitation Research, Office of Special Education and Rehabilitative Services, U.S. Department of Education (grant no. H133A011201).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

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0003-9993/06/8708-10610$32.00/0
doi:10.1016/j.apmr.2006.04.022

THERE HAVE BEEN DRAMATIC improvements in survival after spinal cord injury (SCI) in the 60 years since World War II.[1-14] Several studies[5,6,10,13,14] have suggested the improvements have continued over the last few decades. The possibility of such secular trends is important because it affects the planning of resources for lifelong health care and other needs. Such trends are also of interest because they are likely to be markers for trends in morbidity and for health in general. Furthermore, they are a principal outcome measure for assessing improvements in medical care in SCI over the decades.

Most studies that have investigated such trends have not distinguished the critical first year or 2 after the injury from the subsequent period. The distinction is of interest because although there are reasons to expect improvements in critical care after SCI,[6,10,15-18] the case for longer-term improvements is less clear. In 1 study that excluded the experience of the first postinjury year, DeVivo et al[13] estimated that mortality rates in the 1988 to 1992 period were reduced to 81% of their values in the mid-1970s. This reduction was statistically significant but relatively modest. Furthermore, the downward trend appeared to have reversed direction for their most recent study interval (1993–1998). Similarly, Strauss et al[19] found that the marked secular improvements for the early years postinjury were not matched by the pattern for the subsequent period. The latter, however, was a methodologic article that included a preliminary analysis of trend as an example.

In the present study, these issues were examined by using a larger database with more up-to-date information and more sensitive analytical methods than have been used in most previous studies. As discussed in the Methods section, we analyzed mortality rates on a person-year basis rather than follow a cohort of subjects longitudinally through the whole study period (as in Kaplan-Meier or proportional hazards analysis). This allows us to focus on whether there have been changes in mortality rates over the years, other factors being equal. The main question was whether there has been improved survival since the 1970s in both the immediate postinjury period and in the longer term.

METHODS

Study Population

Data for the present study were collected through the Model Spinal Cord Injury Systems (MSCIS) program and submitted to the National Spinal Cord Injury Statistical Center (NSCISC). As many as 25 SCI centers located around the United States have contributed to this database at various times. Detailed descriptions of the history, eligibility criteria, data collection protocol, data quality control procedures, and current status of the NSCISC database have been published previously.[20,21] This is the largest and most comprehensive source of data on SCI available. Briefly, to be included in the database, people must have (1) had a clinically discernible degree of neurologic (spinal cord) impairment after a traumatic event, (2) been treated at a model system within 1 year of injury, (3) resided in the model system geographic catchment area at the time of injury, and (4) given informed consent.

The study period was 1973 to 2004. Overall, the database included 38,870 people who survived at least 24 hours after injury. Age at injury ranged from 0 to 99 years (mean, 27). There were 7169 deaths over the follow-up period.

Data Collection

The model systems data collectors reported date of death to the NSCISC database whenever, in the course of their routine follow-up data collection activities, they determined an individual to be deceased. In addition, during March and April 2004, the staff of the NSCISC checked on the survival status of persons in the database by searching the Social Security Death Index (SSDI) online at *http://www.ancestry.com*. Persons not reported as deceased by the model system and not found in the SSDI were assumed alive on January 1, 2004. The SSDI has previously been found to be 92.4% sensitive and 99.5% specific for persons in the NSCISC database.[22]

Statistical Methods

The pooled repeated observations method was used for analyzing the datasets.[19] Here the unit of analysis is not a person, as in many survival analyses, but instead a person-year. With each person-year, an outcome variable indicating whether the person lived or died in that year was associated with a set of explanatory variables as listed later. Logistic regression analysis[23] was used to relate the outcome variable to the explanatory variables. This approach has been widely used in related work.[12,24-26] For analysis of secular trends, it is preferable to the cohort approach (eg, proportional hazards modeling[27]) because the focus here is on mortality rates in a given calendar year and whether these rates change over the years, rather than on the experience of persons over long-term follow-up. The analysis was restricted to person-years in which (1) the person was over age 10; (2) the level of neurologic injury was known; (3) the American Spinal Injury Association (ASIA) grade was A, B, C, or D; (4) the person was not ventilator dependent; and (5) the calendar year was between 1973 and 2004 (even though the injury may have been before 1973).

The first restriction was imposed because the effects of injury in childhood, when physiologic development is incomplete, may be different. Long-term survival in young children with SCI will be the subject of a separate report.

For this study, ventilator dependence was defined as partial or total respiratory mechanical support on a long-term daily basis. Ventilator-dependent persons will be the subject of a separate report. Two percent of persons in the database were excluded because of being ventilator dependent at model system discharge, and 10% of persons in the database were excluded because of unknown ventilator status.

After all exclusions, a total of 30,822 persons, 4980 of whom died during the 32-year study period, contributed 323,618.2 person-years to the dataset. (Note that for some of the analyses we required a finer time scale than a year and worked instead with person-tenths-of-a-year. For example, the number of days between injury and entry into the MSCIS database varied considerably and has tended to be shorter in recent years. A subject's first person-tenth-of-a-year begins at the time of entry because survival between injury and entry is in effect guaranteed by his/her presence in the database. By using person-tenths rather than person-years, we were able to specify the time since injury accurately. This avoids bias arising from the higher mortality in the early postinjury period.)

Variables considered in the analyses were as follows.

Level and grade of SCI. The neurologic examination was performed just before model system discharge in accordance with the most current version of the *International Standards for Neurological Classification of Spinal Cord Injury*.[28] Neurologic level of injury was defined as the most caudal segment of the spinal cord with normal sensory and motor function on both sides of the body. The ASIA Impairment Scale (AIS) was used to categorize the extent of injury. Categories were neurologically complete (grade A), incomplete with sensory but not motor function preserved through the S4-5 segment (grade B), incomplete with motor function preserved and more than half of key muscles below the neurologic level having a grade less than 3 out of 5 (grade C), or incomplete with motor function preserved and at least half of key muscles below the neurologic level having a grade of at least 3 out of 5 (grade D).

In this study, level was categorized as high tetraplegia (C1-3), mid tetraplegia (C4 and C5), low tetraplegia (C6-8), and paraplegia (T1-S5). Grade was based on the AIS and divided into 3 groups: A, B and C, and D. There were thus 15 (5×3) combinations of level and grade. However, preliminary analysis showed that the 2 paraplegia categories of grade A and grades B and C did not differ significantly and were combined. Similarly, the 5 categories of grade D were also combined.

Age. For the effect of age on mortality, 2 linear terms, 1 for grades A, B, and C and 1 for grade D, appeared preferable to the inclusion of separate terms for each 5- or 10-year age group.[13] Under these linearity assumptions, the log-odds on dying increases by the same amount for each extra year of age.

Sex. Sex was coded as male or female.

Ethnicity. A white and nonwhite classification was retained to make the study comparable to previous work,[9,13] even though the difference did not prove to be significant in the present study.

Etiology of injury. Preliminary analyses indicated that personal violence (eg, as opposed to an accident) was the only etiology of injury that had significant predictive value. As noted elsewhere,[13] an etiology of violence tends to be associated with poorer socioeconomic class and nonwhite ethnicity.

Time since injury. As reported in previous work, mortality was greatest in the first 2 years after injury. A term for the period 24 to 36 months after injury was retained because mortality was somewhat higher then than after the third anniversary of injury. For the period after the third anniversary, mortality appeared to be entirely independent of time since injury, other factors being equal, and therefore this period was not stratified in the models reported here.

Calendar year. How mortality risk has changed over the years, other factors being equal, was the central issue in the present study. Calendar years were originally broken into the intervals 1973 to 1979, 1980 to 1989, 1990 to 1999, and 2000 to 2004. Analysis showed no appreciable difference between the last 2 of these, and they were thus combined.

Model selection was performed by using Wald and deviance statistics for nested models, and the Akaike information criterion otherwise.[27(p79)] The latter is formally similar to the usual deviance statistic for comparing 2 models, but it applies when 1 model is not "nested" within the other. For the analyses, the dataset was separated into subsets according to time since injury. Preliminary analysis indicated that it was appropriate to work with 2 subsets, according to whether the time since injury was more or less than 2 years. Life table methods[29,30] were used to determine life expectancy (average number of additional years of life in a large group of similar persons) for 25-year-old white males with nonviolent etiology who had already survived more than 2 years postinjury. This combination of age, sex, and ethnicity was chosen as an example because it is among the most commonly occurring patterns among persons with SCI.

Table 1: Subjects' Characteristics, by Period of Injury

Characteristics	Period 1973–1979	1980–1989	1990–2004
No. of injured persons entering system	5438	10,988	13,716
No. died	1592	2112	1125
Men	81	82	79
Age at injury (y)			
10–20	29	23	21
20–30	37	38	28
30–40	15	18	20
40–50	9	9	14
50–60	5	6	8
60+	5	6	9
Injury level and ASIA grade			
C1-4, grade A	5	5	6
C1-4, grades B and C	2	3	5
C5-8, grade A	18	14	11
C5-8, grades B and C	10	10	8
T1-S5, grade A	31	28	34
T1-S5, grades B and C	7	8	10
Grade D, all levels	27	32	26

NOTE. Values are percentages unless otherwise noted.

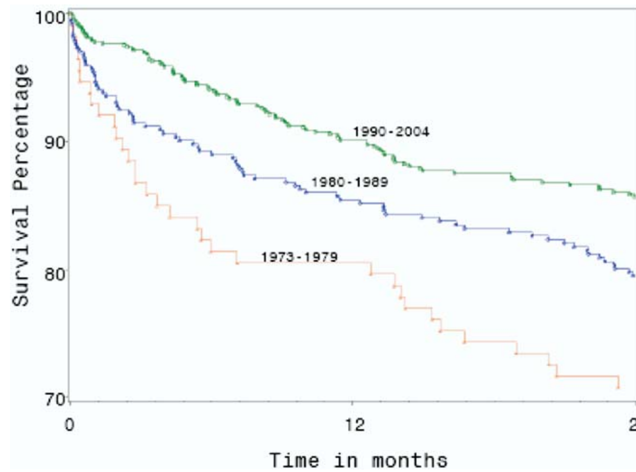

Fig 1. Two-year Kaplan-Meier survival curves for C1-4 grade A, B, and C injuries by period of injury; age greater than 30.

RESULTS

The data were stratified into 3 time periods, as indicated in table 1: 1973 to 1979, 1980 to 1989, and 1990 to 2004. Table 1 shows how the subjects in each of the injury periods were distributed according to age, sex, injury level, and grade. It may be noted that the subjects in the late period were slightly more likely to be in the most severe group (C1-4), which may indicate a trend over time toward improved survival in this group until entry to the MSCIS. More strikingly, the percentage of injured persons who are older has increased over time. For example, in the 1970s, only 34% of the subjects were of age 30 or more at time of injury compared with 51% in the late period. The reasons for this are related to etiologies of injury and the aging general population. A detailed discussion of these demographic trends in the NSCISC database has been published.[31] Because subjects in the late period tend to have more severe injuries and to be older, both negative factors for life expectancy, it is necessary to control for these factors when survival in different time periods is compared.

Figure 1 shows the Kaplan-Meier survival plots for the first 2 years of survival for the same periods of injury as described earlier. To control for these factors, we considered only persons over the age of 30 who had C1-4 injuries of grade A, B, or C. The graph shows much higher mortality rates during the earliest of the 3 time periods than during the latest time period (71% vs 86% survival).

Table 2 shows the results of a logistic regression model applied only to the time between admission to the MSCIS and the second anniversary of injury. The model and following findings are similar to those reported by DeVivo and Stover[9] in their proportional hazards analysis of survival over the whole postinjury period.

1. Being white is a modestly positive factor for survival, whereas male sex and an etiology of personal violence (rather than an accident) are modestly negative factors.
2. The odds on dying in a given person-year increase steadily with age, by 7% per year (not per tenth-of-a-year). Following DeVivo and Stover,[9(tbl14.3)] we used a simple linear age-trend term to model the odds on dying; the inclusion of separate terms for each 5-year (or 10-year) age group proved not to be necessary according to the Akaike information criterion (ie, the data were consistent with the assumption that the log odds on dying increase by the same amount per year at every age).
3. Among persons with complete (grade A) injuries, mortality rates are considerably higher for those with high tetraplegia (the C1-3 group) than for mid (C4 or C5) to low tetraplegia (C6-8), and the latter in turn have higher mortality than for paraplegia. The same pattern was observed for incomplete injuries of grades B and C, with the exception of a nonsignificant reversal for C6 to C8 and paraplegic injuries.

Table 2: Logistic Regression Model for Prediction of Mortality for Less Than 2 Years Since Injury

Variable	Odds Ratio	95% CI
Male	1.220	1.04–1.44
White	0.840	0.73–0.97
Violence	1.420	1.16–1.74
Age	1.073	1.07–1.08
C1-3, grade A	17.114	11.6–25.2
C4, grade A	8.212	6.40–10.5
C5, grade A	6.952	5.38–8.99
C6-8, grade A	3.202	2.40–4.26
C1-3, grades B and C	4.272	2.57–7.09
C4, grades B and C	3.229	2.45–4.25
C5, grades B and C	2.780	2.06–3.75
C6-8, grades B and C	1.927	1.37–3.72
T1-S5, grades A, B, and C	2.218	1.83–2.70
Grade D and E	1.000	NA
Time since injury 0.0 to 0.3y	2.658	2.17–3.25
Time since injury 0.3 to 1.5y	1.366	1.14–1.64
Time since injury 1.5 to 2.0y	1.000	NA
Years 1973–1979	1.000	NA
Years 1980–1989	0.786	0.65–0.95
Years 1990–2004	0.613	0.51–0.74

NOTE. 475,310 person-tenths-of-a-year, 959 deaths.
Abbreviations: CI, confidence interval; NA, not applicable.

Table 3: Logistic Regression Model for Prediction of Mortality for More Than 2 Years Since Injury

Variable	Odds Ratio	95% CI
Male	1.303	1.20–1.42
White	1.017	0.95–1.09
Violence	1.225	1.11–1.35
Age, grades A, B, and C	1.063	1.06–1.07
Age, grade D	1.073	1.07–1.08
C1-3, grade A	7.439	5.00–11.1
C4, grade A	6.825	5.13–9.09
C5, grade A	5.069	3.81–6.75
C6-8, grade A	3.539	2.67–4.69
C1-3, grades B and C	4.279	2.73–6.71
C4, grades B and C	3.509	2.55–4.82
C5, grades B and C	3.286	2.42–4.47
C6-8, grades B and C	3.054	2.27–4.12
T1-S5, grades A, B, and C	2.855	2.17–3.75
Grade D and E	1.000	NA
Time since injury 2.0 to 3.0y	1.114	0.98–1.27
Time since injury ≥3.0y	1.000	NA
Years 1973–1979	1.000	NA
Years 1980–1989	0.829	0.67–1.03
Years 1990–2004	0.856	0.69–1.06

NOTE. 2,760,870 person-tenths-of-a-year, 4021 deaths.

4. The terms for time since injury (TSI) 0.0 to 0.3 and TSI 0.3 to 1.5 refer to the person-tenths-of-a-year whose times since injury are between 0.0 to 0.3 years and 0.3 to 1.5 years, respectively. The reference category is TSI between 1.5 and 2.0 years. The odds ratios of 2.66 and 1.37 indicate that mortality is extremely high in the first three tenths of a year after injury and is almost twice as large as in the subsequent 1.2 years after that initial period. This reflects the high mortality risk in the immediate months after an SCI.

The results shown in table 2, however, also reveal the following findings that have not previously been reported:

1. Among those with high cervical injuries (C1-3), mortality rates are dramatically higher for those with complete (ASIA grade A injuries) than for those with incomplete (grades B or C) injuries. Table 2 shows that during the first 2 years, those with complete injuries have a relative risk of 4.0 (=17.11/4.27) compared with those with incomplete injuries.
2. A similar, although less extreme, finding held for those with midlevel (C4 or C5) cervical injuries and low (C6-8) cervical injuries, with relative risks of 2.5 and 1.7, respectively. Again, relative risks are for complete versus incomplete (grade B or C) injuries.
3. Among those with paraplegia, no significant difference was found between ASIA grade A, B, or C injuries. Thus, the distinction between these injury grades is an important one for those with the highest levels of injury but not so for those with lower injuries.
4. Although not shown in table 2, within the group of paraplegic injuries (T1-S5) there appeared to be a relation between level of injury and mortality. Specifically, those with high thoracic injuries (T1-6) had somewhat higher mortality. Such a difference may be biologically plausible in that high thoracic injuries may involve compromise of the respiratory function.
5. Of particular interest is the strong secular trend in survival during the first 2 years postinjury. In the middle period (1980–1989), the odds on dying were only 79% of their values in the early period (1973–1979), and this dropped to 61% during the late period (1990+). As noted, there were no significant differences within this late period. Thus, mortality odds during the first 2 years postinjury decreased by 39% from the 1970s to the current period. This finding is broadly similar to that reported by DeVivo and Stover[9] for the whole postinjury period and roughly corresponds to the relative mortality risk observed in figure 1. Furthermore, the secular trend did not differ significantly according to level or grade of injury or other factors that were considered.

Table 3 used essentially the same model as table 2, the difference being that the data considered were based on time since injury more than 2 years rather than less than 2 years. Many of the results from this analysis are similar to those of table 2, including the effects of male sex, being white, etiology of personal violence, and the pattern of mortality in the various groups based on level and grade of injury. In contrast to table 2, the rate of increase in mortality per year of age was appreciably different (by 1% per year) for persons with grades A, B, and C injury and those with grade D injury. Once again, a substantial difference in survival was found in complete versus incomplete grade B or C injuries: relative risks of 1.7 and 1.9 in the C1-3 and C4 groups, decreasing to 1.5 in the C5 group and to 1.2 in the C6-8 group. As noted, the relative risk was approximately 1.0 (ie, no difference) for those with paraplegia.

The striking difference between tables 2 and 3 is that the latter shows no substantial trend in survival over time. Although the data suggest that mortality rates decreased slightly, by about 17%, after the 1970s, this rather small difference proved not to be statistically significant. Furthermore, there was no evidence at all for any decline over the 25-year period of 1980 to 2004. The conclusion is that after the critical first 2 years postinjury, there is no evidence of a major improvement in survival over the 30-year study period once age, level and grade of injury, and so on were taken into account. Various regroupings of the time periods were considered, but these also failed to yield any significant trend in survival over time. Furthermore, there were again no significant interactions (ie, there was no evidence of a trend for some subgroups of patients).

Most previous work on life expectancy of persons with SCI has combined subjects with complete (grade A) and incomplete (grades B and C) injuries. Therefore, the effect of making this distinction was examined by using the new findings reported in table 3. For illustration, table 4 shows life expectancies for a

Table 4: Sample Life Expectancies for 25-Year-Old White Man: Nonviolent Etiology and Time Since Injury 3 Years, by Injury Level and ASIA Grade

Group	Life Expectancy (y)
General population	50.9
C1-3, grade A	25.4
C1-3, grades B and C	32.2
C4, grade A	26.4
C4, grades B and C	34.9
C5, grade A	30.0
C5, grades B and C	35.7
C6-8, grade A	34.7
C6-8, grades B and C	36.7
T1-S5 (paraplegia), grades A, B, and C	37.6
All grade D	44.7

white male of age 25 injured 3 years ago with a nonviolent injury etiology. As may be seen, for a C1-3 injury, the complete versus incomplete grade B or C distinction makes an estimated 6.8-year difference in life expectancy. For a C4 injury, the difference in life expectancy is 8.5 years, and for a C5 injury the difference decreases to 5.7 years. For C6-8 injuries, the difference in life expectancy is much smaller (2.0y), and for paraplegia no significant difference was observed. As may be expected, the life expectancies reported in DeVivo and Stover's table 3 for grades A, B, and C combined are intermediate to the figures shown here in table 4 for A and for B and C separately.[9]

DISCUSSION

The primary focus of this study was an investigation of improvements in survival in mortality after SCI since the 1970s. There were dramatic improvements for the first 2 postinjury years, which is consistent with previous reports. The principal findings, however, were that for the subsequent period there was at most a modest improvement since the 1970s and no evidence for any improvement after 1980.

Although these findings may appear to be inconsistent with previous research, this is not the case. For example, the 1999 U.S. study by DeVivo et al began, "In the past several decades, acute and long-term survival rates for persons with spinal cord injury (SCI) have improved dramatically. . ."[13(p1411)] and cited 16 studies. Most of these studies, however, were based on data before 1980 and did not stratify the results according to time since injury (eg, the first 2y postinjury and the subsequent period).

Perhaps the most relevant of the previous studies is the previously cited 1999 article itself.[13] Its table 1, which gives the results of proportional hazards regression modeling of mortality during the first year after injury only, shows a dramatic decline in mortality since the 1970s. However, table 2 of that study, which follows the subjects after the first postinjury year, indicates only a 9% decline in odds on dying from the 1973 to 1977 period to 1983 to 1987 and a 19% decline to 1988 to 1992. In the final period, 1993 to 1998, the trend appeared to reverse, with mortality rates if anything higher than those in the 1970s.

To our knowledge, the only other work on recent trends in SCI mortality is the U.K. study by Frankel et al,[5] who considered survival of persons alive 12 months after their injuries. These authors reported a 33% decline in mortality, after adjustment for various risk factors, from 1973 to 1982 to 1983 to 1990 (the latest period considered in the study). The 95% confidence interval for the reduction was rather wide, ranging from 8% to 51%, and is thus not inconsistent with the results reported here. Furthermore, it seems likely that smaller reductions would have been obtained if the first 2 years after the injury, rather than the first year, had been excluded.

It is conceivable that 1 consequence of improvements in critical care is the postponement of some deaths that would previously have occurred during the first 2 postinjury years. If such deaths now tend to occur in the subsequent period rather than the earlier period, it would (1) partly explain the decline in acute-period mortality over time and (2) offset any improvements that may have occurred in the long-term period. Although this postponement-of-mortality theory cannot easily be disproved, it is unlikely to be a major factor in the results reported here. For example, if it were true, then (when age and other factors are controlled) the mortality rates between 3 to 5 years postinjury would be substantially higher than those for 10 to 20 years postinjury. As noted in the Methods section, this was not the case.

There have been anecdotal reports that because of modern critical care techniques and more rapid transfer of patients to specialist facilities, it is often possible to preserve the level of injury or ASIA grade at a less severe level than previously. We are not aware of any formal studies on this. If it were true, however, it would indicate a hidden improvement in survival over time; the effect would disappear in any statistical analysis that compared mortality rates after the level of injury was taken into account.

The pattern of causes of death to persons with SCI over recent decades deserves attention. If mortality after the second anniversary of injury has indeed declined dramatically over recent decades, one would expect a marked shift in the pattern. Death rates from major risk factors in the SCI population, such as respiratory infections, would be expected to have declined more than conditions such as heart disease and cancer, which are the main causes of death in the general population. If this were so, the proportions of deaths from the various causes would have changed substantially over time. The available evidence suggests that this is not the case. The largest and most detailed investigation appears to be that of DeVivo,[13] who analyzed 1543 deaths occurring beyond the first year after injury. After controlling for age, severity of injury, and other factors, they found no significant trends in cause-specific proportions of deaths. The sole exception was diseases of the genitourinary system, whose proportion declined significantly during the final 6 years of the study period.

A relatively recent work on this topic is the U.K. study of Frankel.[5] It has the advantage of giving direct comparisons of cause-specific mortality rates over time, after adjustment for age and sex. The picture here was somewhat mixed. Frankel[5] reported a marked decline in deaths from urinary tract infections over their 50-year study period. There was also a steady decline in heart disease mortality, which mirrors the decline observed in the general population and is not obviously reflective of changes in the treatment of patients with SCI. However, with respect to respiratory infections, which are now the leading cause of death in this population, Frankel found no statistically significant trend, "suggesting that the risk of dying from these causes has remained relatively constant over the last 50 years."[5(p271)]

DeVivo[13] note that there has been widespread concern about the influence of managed care on the quality of the U.S. health care system. They found significant differences in mortality rates according to the sponsor of health care (eg, Medicare or health maintenance organizations [HMOs]). More recently, Krause et al[12] reported that coverage through worker's compensation, as opposed to other sponsorship of care, was a strong positive factor for survival, even after control for age and severity of injury. The issue is complex, however, because various selection biases operate. For example, HMOs may select against patients with the greatest medical needs, and recipients of worker's compensation, being in the workforce before injury, are on average in better health initially than those not in the workforce. Whether changes in the health care system have affected mortality after SCI is not yet clear.

From a methodologic point of view, a strength of the present study is its use of person-years rather than persons as the unit of analysis. This approach, used here, allows one to focus on mortality rates for a given calendar year or time since injury, rather than on the risks of persons over a long follow-up period. In this way, it is straightforward to compare mortality rates in different periods or to stratify according to time since injury. This is technically possible in the context of proportional hazards modeling with time-varying covariates but is more cumbersome.[19]

The present study has been restricted to persons with SCI who are not ventilator dependent. Recent work on ventilator-dependent persons in the NSCISC database has indicated a similar pattern to that reported here. There has been a marked improvement over the last 30 years in the survival of such persons during the first 3 years after injury (and especially in the first year) but no significant improvement for the post 3-year period (RM Shavelle, PhD, et al, unpublished data, 2006).

Further comparison may be made to work on mortality trends in cerebral palsy (CP) and other developmental disabilities. A dramatic improvement in survival over recent decades has been reported for infants in the vegetative state.[26] For adults with CP, however, the pattern appears to be quite different. A recent study examined the pattern of mortality over the last 20 years in a large California population of persons with CP.[32] For persons of age 15 and over, the authors found substantial improvements over time in the small subset of subjects who required gastrostomy feeding (these were generally the most severely disabled people) but only a weak and marginally significant trend otherwise. There are, of course, considerable differences in rehabilitation medicine for persons with CP and SCI. Nevertheless, the similarity of the findings in the 2 conditions is striking: marked improvements over recent decades in "critical care" mortality and at best a minimal improvement in long-term mortality.

Finally, it is important to note the contrast between survival after complete (grade A) and incomplete (grade B or C) injuries. For high tetraplegia (levels C1-4), the distinction is a significant one for life expectancy, making a difference of approximately 7 years for a young adult. The difference is smaller for low tetraplegia (C5-8), and no discernable difference was observed in paraplegia (T1 and below). A similar finding was reported by Coll et al[33] in their analysis of U.K. SCI data. In the estimation of the life expectancy of persons with tetraplegia, it may be appropriate to distinguish between complete and incomplete (grade B or C) injuries.

There are several limitations of the present study. First, the NSCISC database is not population based. It only captures data from approximately 13% of the persons who have sustained SCI in the United States and only from persons who are treated at the MSCIS.[20] It is possible that persons who are not treated at the MSCIS experience different short-term and long-term mortality rates and that the trend in mortality rates for those persons might be different than the trend for persons who are treated at the MSCIS.

Another limitation is that the NSCISC database does not include information on many factors such as smoking history, associated injuries, or preexisting major medical conditions that might be of prognostic importance in determining life expectancy. If there were trends in these potentially important prognostic factors, it would confound the assessment of overall trends in mortality over time.

Missing and incomplete data represent another limitation of this study. As already noted, 10% of persons in the database were excluded from the study because of missing information on ventilator status. Most of these persons have high level neurologically complete cervical injuries, causing this neurologic group to be underrepresented in the study. Some other persons had missing neurologic data. Missing neurologic data occur disproportionately among persons who die soon after injury before an accurate assessment of neurologic status can be made. As a result, the odds ratios for time since injury reflected in table 2 are probably slightly underestimated.

As already noted, the SSDI is 92.4% sensitive in identifying deceased persons. Although this was not the only method of identifying deceased persons, it is likely that a few persons who died were misclassified as alive, thereby causing a slight overestimation of life expectancy. In a recent study of deceased persons with traumatic brain injury, young age, being unmarried, and being female all significantly decreased the sensitivity of the SSDI.[22] Moreover, if sensitivity of the SSDI changed over time, this would affect the analysis of mortality trends.

CONCLUSIONS

This study confirms the substantial progress that has occurred over the past 30 years in reducing the mortality rate during the first 2 years after SCI. As a result, life expectancy measured from the time of injury has also increased substantially. However, the study also shows that since 1980 there has been no substantial change in either annual mortality rates after the second postinjury year or in life expectancy as measured from the second anniversary of injury or later. However, the National Center for Health Statistics reports that the life expectancy for a 25-year-old white man from the U.S. general population has increased from 47.8 years in 1980 to 51.4 years in 2004. Therefore, the gap between life expectancies of persons with SCI who have already survived at least 2 years postinjury and comparable individuals from the general population may have actually increased. At a minimum, there is no evidence that the gap has narrowed. Additional studies of the latest causes of death among persons with SCI are needed to better understand the reasons for this lack of longer-term progress in reducing annual mortality rates.

Until such cause of death studies are performed, we must rely on existing literature[9,13] that indicates pneumonia and septicemia to have the highest long-term standardized mortality ratios, with heart disease also causing a high percentage of premature deaths. Routine annual screenings and follow-ups are important for prevention and early treatment of secondary medical complications. Pneumococcal vaccine should be given during initial hospitalization and will likely need to be repeated over time.[34] Influenza vaccine should be given annually. Long-term monitoring of the skin and urinary tract and aggressive treatment of pressure ulcers and symptomatic urinary tract infections is needed to reduce the risk of septicemia. Smoking cessation and appropriate nutrition and exercise must also be encouraged to reduce the risk of cardiovascular disease. Given the current cause of death profile, these activities would likely have the greatest immediate impact on improving life expectancy.

References

1. Mesard L, Carmody A, Mannarino E, Ruge D. Survival after spinal cord trauma. A life table analysis. Arch Neurol 1978;35:78-83.
2. Kiwerski J, Weiss M, Chrostowska T. Analysis of mortality of patients after cervical spine trauma. Paraplegia 1981;19:347-51.
3. Le CT, Price M. Survival from spinal cord injury. J Chronic Dis 1982;35:487-92.
4. DeVivo MJ, Kartus PL, Stover SL, Rutt RD, Fine PR. Seven-year survival following spinal cord injury. Arch Neurol 1987;44:872-5.
5. Frankel HL, Coll JR, Charlifue SW, et al. Long-term survival in spinal cord injury: a fifty year investigation. Spinal Cord 1998;36:266-74.
6. DeVivo MJ, Stover SL, Black KJ. Prognostic factors for 12-year survival after spinal cord injury [published erratum appears in Arch Phys Med Rehabil 1992;73:1146]. Arch Phys Med Rehabil 1992;73:156-62.
7. Whiteneck GG, Charlifue SW, Frankel HL, et al. Mortality, morbidity and psychosocial outcomes of persons spinal cord injured more than 20 years ago. Paraplegia 1992;30:617-30.

8. Samsa GP, Patrick CH, Feussner JR. Long-term survival of veterans with traumatic spinal cord injury. Arch Neurol 1993; 50:909-14.
9. DeVivo MJ, Stover SL. Long-term survival and causes of death. In: Stover SL, DeLisa JA, Whiteneck GG, editors. Spinal cord injury: clinical outcomes from the model systems. Gaithersburg: Aspen; 1995. p 289-316.
10. Hartkopp A, Bronnum-Hansen H, Seidenschnur AM, Biering-Sorensen F. Survival and cause of death after traumatic spinal cord injury. A long-term epidemiological survey from Denmark [published erratum appears in: Spinal Cord 1997;35:862-4]. Spinal Cord 1997;35:76-85.
11. Strauss D, DeVivo MJ, Shavelle R. Long-term mortality risk after spinal cord injury. J Insur Med 2000;32:11-6.
12. Krause JS, DeVivo MJ, Jackson AB. Health status, community integration, and economic risk factors for mortality after spinal cord injury. Arch Phys Med Rehabil 2004;85:1764-73.
13. 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;80:1411-9.
14. Imai K, Kadowaki T, Aizawa Y. Standardized indices of mortality among persons with spinal cord injury: accelerated aging process. Ind Health 2004;42:213-8.
15. Belanger E, Levi AD. The acute and chronic management of spinal cord injury. J Am Coll Surg 2000;190:603-18.
16. Griffin MR, O'Fallon WM, Opitz JL, Kurland LT. Mortality, survival and prevalence: traumatic spinal cord injury in Olmsted County, Minnesota, 1935-1981. J Chronic Dis 1985;38:643-53.
17. Gunnarsson T, Fehlings MG. Acute neurosurgical management of traumatic brain injury and spinal cord injury. Curr Opin Neurol 2003;16:717-23.
18. Hadley MN, Walters BC. Guidelines for management of acute cervical spine and spinal cord injuries. Section on disorders of the spine and peripheral nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons. Rolling Meadows: American Association of Neurological Surgeons; 2002.
19. Strauss D, Shavelle R, DeVivo MJ, Day S. An analytic method for longitudinal mortality studies. J Insur Med 2000;32:217-25.
20. Stover SL, DeVivo MJ, Go BK. History, implementation, and current status of the National Spinal Cord Injury Database. Arch Phys Med Rehabil 1999;80:1365-71.
21. DeVivo MJ, Go BK, Jackson AB. Overview of the national spinal cord injury statistical center database. J Spinal Cord Med 2002; 25:335-8.
22. DeVivo MJ, Underhill AT, Fine PR. Accuracy of world-wide-web death searches for persons with traumatic brain injury. Brain Inj 2004;18:1155-62.
23. Hosmer D, Lemeshow S. Applied logistic regression. 2nd ed. New York: Wiley; 2000.
24. Cupples A, D'Agostino RB, Anderson K, Kannel WB. Comparison of baseline and repeated measure covariate techniques in the Framingham Heart Study. Stat Med 1998;7:205-18.
25. Singer JD, Willett JB. Modeling the days of our lives: using survival analysis when designing and analyzing longitudinal studies of duration and the timing of events. Psychol Bull 1991;110: 268-90.
26. Strauss DJ, Shavelle RM, Ashwal S. Life expectancy and median survival time in the permanent vegetative state. Pediatr Neurol 1999;21:626-31.
27. Collett D. Modelling survival data in medical research. London: Chapman & Hall; 1994.
28. American Spinal Injury Association. International standards for neurological classification of spinal cord injury. Chicago: ASIA; 2002.
29. Schoen R. Modeling multigroup populations. New York: Plenum Pr; 1988. ch 1.
30. Strauss DJ, Vachon PJ, Shavelle RM. Estimation of future mortality rates and life expectancy in chronic medical conditions. J Insur Med 2005;37:20-34.
31. Jackson AB, Dijkers M, DeVivo MJ, Poczatek RB. A demographic profile of new traumatic spinal cord injuries: change and stability over 30 years. Arch Phys Med Rehabil 2004;85:1740-8.
32. Strauss D, Shavelle R, Reynolds R, Rosenbloom L, Day S. Improved survival in cerebral palsy? Dev Med Child Neurol. In press.
33. Coll JR, Frankel HL, Charlifue SW, Whiteneck GG. Evaluating neurological group homogeneity in assessing the mortality risk for people with spinal cord injuries. Spinal Cord 1998;364: 275-9.
34. Waites KB, Canupp KC, Edwards K, Palmer P, Gray BM, DeVivo MJ. Immunogenicity of pneumococcal vaccine in persons with spinal cord injury. Arch Phys Med Rehabil 1998;79:1504-9.