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ORIGINAL ARTICLE

Long-term Mortality Risk After Spinal Cord Injury

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We studied long-term mortality in a sample of 19,226 persons with spinal cord injury. Subjects were grouped into 4 categories on the basis of neurological lesion (which depends on how high the injury is on the spinal column) and on the severity of impact (Frankel grade). Excess death rates tended to increase with age in each category, while mortality ratios tended to decrease.

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Spinal cord injury is one of the most prevalent causes of long-term disability. In the United States, more than 200,000 persons have such injuries, and more than 10,000 new cases occur each year.[1] Despite great improvements in care, particularly during the critical months immediately after injury,[2] life expectancy for persons with spinal cord injury is still substantially reduced.[3]

The largest and most comprehensive source of data on spinal cord injury is the Model Spinal Cord Injury Systems program, a network of 18 centers from around the United States. Much of the research on the Model Systems Uniform Database, including most of the work on mortality, is conducted by the National Spinal Cord Injury Statistical Center in Birmingham, Ala. For a summary up to 1995 of the extensive literature on long-term survival after spinal cord injury, see DeVivo and Stover.[3] Most recently, Frankel et al[4] and Coll et al[5] have reported on mortality in British spinal cord patients. DeVivo et al[6] have studied causes of the mortality after spinal cord injury.

Our focus in this article is on mortality data that may be useful to medical directors of life insurance companies and others concerned with insurance risks. We compare mortality of spinal cord patients with that of the general population for persons with different categories of neurological lesions and levels of severity of disability. The data are drawn from the National Model Systems Database, augmented by additional records maintained by one of us (M.J.D), of persons with spinal cord injuries who were treated at model systems but were not eligible for the National Model Systems Database. In all, 19,226 subjects injured since 1973 were alive

and in follow-up after the second anniversary of injury.

The period shortly after spinal cord injury is one of especially high risk. Published work (eg, figure 14.2 of DeVivo and Stover) and unpublished investigations by us suggest that mortality risk stabilizes approximately 2 years after injury, and thereafter the effect of time since injury on current risk is relatively minor. Because our interest here is in long-term mortality, we have only considered exposure to and occurrence of mortality for the period beginning 2 years after the injury.

Our analysis is based on a grouping of patients at discharge from inpatient rehabilitation, using the neurological level of the spinal injury and the Frankel grade of severity. Neurological level refers to the highest vertebra where the spinal cord is injured. This could be any of the 8 cervical vertebrae (such cases are referred to as C1–C8), down to thoracic, lumbar, or sacral injuries. Other things equal, the higher level injuries result in more complete disabilities. In particular, C1–C8 injuries generally result in tetraplegia or tetraparesis, while the lower levels are associated with paraplegia. Frankel grades are A (complete), B (incomplete, preserved sensation only), C (incomplete, preserved motor nonfunctional), D (incomplete, preserved motor functional), and E (normal); see, for example, Ditunno et al.[7] The 4 categories used here are C1–C4, ABC (most severe); C5–C8, ABC; all paraplegia, ABC; and all Frankel grade D. Although other, more complex schema have been employed, this classification is the current standard.

Other factors associated with mortality risk, including sex, ethnicity, ventilator dependence, and year of injury, are not taken into account in this study. We will return to these issues in the "Discussion" section.

RESULTS

Characteristics of the 19,226 persons with spinal cord injury are given in Table 1. It can be seen, for example, that people in the most severe group (C1–C4, ABC) suffer the highest mortality and are the most likely to be ventilator dependent.

Table 2 gives mortality statistics for the C1–C4, ABC group. As noted, data are drawn from the period following patients' second anniversary of injury. The mortality ratio for all ages combined is 510%. Note that the age-specific mortality ratios tend to decline with age, whereas the excess death rates (observed minus expected) tend to increase. This pattern, which holds for the other 3 groups (Tables 3 through 5), has also been observed for chronic conditions such as cerebral palsy.[8]

The mortality rates (q) of Tables 2 through 5 were used to construct life tables and compute life expectancies for the 4 groups (Table 6). Under our simplifying assumption that since injury is not a factor after 2 years, the results may be taken to apply to a cohort of persons already 2 years or more postinjury and with the same male and female proportions as in the database. Note that the computations are based entirely on empirical mortality rates. This differs from the use of model-based rates, as in some studies of cerebral palsy,[9] spinal cord injury,[10] and other conditions.[11]

DISCUSSION

Because our analysis was based on a large group of subjects with spinal cord injury, we were able to study age-specific mortality rates and ratios in some detail. As in previous work on cerebral palsy, we found that mortality ratios tended to decline with age and excess death rates tended to increase. One consequence is that life expectancies based on an assumption of constant mortality ratio will be too low, and those based on constant excess risk will be too high.

Our analysis has focused on age, neurological level, and Frankel grade as determinants of mortality rates and life expectancies.

Other factors that have been shown to play a role include time-varying characteristics such as ventilator dependence and functional level, as well as "static" factors such as ethnicity, sex, and year of injury. In effect, our

Table 1. Characteristics of Subjects With Spinal Cord Injury*

Variable	Group					
	C1–C4 ABC	C5–C8 ABC	All Paraplegics ABC	All D	Grade E or Unknown	Total
Number	1915	4656	6729	4732	1194	19,226
Survived						
Yes	83.3%	88.1%	90.2%	90.8%		17,077
No	16.7	11.9	9.8	9.2		2149
Age						
0–9	1.3	1.0	2.6	0.9		306
10–19	27.2	28.3	21.6	20.2		4503
20–29	35.5	38.9	39.1	32.7		7076
30–39	16.9	16.0	19.5	17.5		3425
40–49	8.1	8.7	9.6	12.1		1919
50–59	5.6	3.7	4.5	8.9		1084
60–69	4.2	0.5	2.4	5.6		660
70–79	1.0	0.8	0.7	1.8		219
80+	0.3	0.1	0.1	0.3		34
Sex						
Male	86.2	82.5	80.0	80.0		15,581
Female	13.8	17.5	20.1	20.0		3645
Race						
Caucasian	73.7	76.0	68.1	72.1		13,816
African American	17.9	14.8	19.2	18.5		3384
Hispanic	5.5	6.6	9.1	7.1		1425
Other	3.0	2.4	3.2	2.3		541
Ventilator dependence at discharge						
No	80.2	87.3	90.9	88.4		16,324
Yes	10.8	0.6	0.1	0.3		264
Unknown	9.0	12.2	9.0	11.3		2638
Year of injury						
1973–79	23.9	33.0	30.0	30.1		6077
1980–88	48.4	45.4	43.5	51.7		8815
1989–96	27.7	21.6	26.5	18.2		4334

* A total of 18,030 subjects were Frankel grade D or worse at discharge and were alive and in follow-up on second anniversary of injury. The 1196 subjects rated Frankel grade E (normal) at discharge are not included in the main table.

results are averaged over these factors. As shown by DeVivo and Stover, ventilator dependence in particular is associated with a large reduction in life expectancy. These researchers also found a strong secular trend, mortality for those injured in 1989–92 being only 58% of what it was 25 years earlier. It may be that much of the improvement occurs during the initial intensive care period, rather than in the very long term. To the extent that long-term survival has improved, however, mortality rates given here may be overestimates for recently injured persons.

The life expectancies reported in Table 6 decrease down each column (ie, as age increases within each disability grouping), with the exception of 2 reversals in the group with the highest mortality rates, C1–C4 ABC. Such reversals are mathematically possible, but uncommon. We note that the life-table analysis in Table 6 takes the conventional approach of using empirical age-specific mortality rates,

Table 2. Tetraplegics (C1–C4), Frankel Grades ABC

Attained Age	Exposure, Person-Years (E)	No. Deaths		Mortality Ratio (100 d/d')	Mean Annual Rate per 1000		
		Observed (d)	Expected* (d')		Observed (q)	Expected* (q')	Excess ($q - q'$)
10	95	3	0.06	4986%	31.58	0.63	30.95
15	606	5	0.68	733%	8.25	1.12	7.13
20	2459	28	3.65	768%	11.39	1.48	9.90
25	3223	26	5.34	487%	8.07	1.66	6.41
30	3080	41	6.39	642%	13.31	2.07	11.24
35	2339	40	6.20	645%	17.10	2.65	14.45
40	1457	38	4.85	784%	26.08	3.33	22.75
45	804	26	3.64	715%	32.34	4.52	27.81
50	538	22	3.77	583%	40.89	7.01	33.88
55	370	18	4.04	445%	48.65	10.93	37.72
60	317	16	5.31	301%	50.47	16.77	33.71
65	275	21	7.00	300%	76.36	25.46	50.91
70	166	20	5.93	337%	120.48	35.73	84.76
75	53	9	2.58	349%	169.81	48.64	121.17
80	31	4	2.67	150%	129.03	86.21	42.83
All	15,813	317	62.11	510%	20.05	3.93	16.12

* Expected number based on 1992 US Life Table rates for males and females.

Table 3. Tetraplegics (C5–C8), Frankel Grades ABC

Attained Age	Exposure, Person-Years (E)	No. Deaths		Mortality Ratio, % (100 d/d')	Mean Annual Rate per 1000		
		Observed (d)	Expected* (d')		Observed (q)	Expected* (q')	Excess ($q - q'$)
10	131	0	0.06	0	0.00	0.49	−0.49
15	1464	5	1.51	330	3.42	1.03	2.38
20	6420	29	9.06	320	4.52	1.41	3.11
25	8774	51	14.15	360	5.81	1.61	4.20
30	8465	63	17.17	367	7.44	2.03	5.41
35	6743	83	17.39	477	12.31	2.58	9.73
40	4256	59	13.89	425	13.86	3.26	10.60
45	2567	56	11.18	501	21.82	4.35	17.46
50	1659	45	10.90	413	17.12	6.57	20.56
55	1078	32	11.34	282	29.68	10.52	19.17
60	763	34	12.70	268	44.56	16.64	27.92
65	479	33	12.30	268	68.89	25.68	43.21
70	282	33	10.73	308	117.02	38.05	78.97
75	118	15	6.68	225	127.12	56.57	70.55
80	68	12	6.00	200	176.47	88.26	88.21
All	43,267	550	155.06	355	12.71	3.58	9.13

* Expected number based on 1992 US Life Table rates for males and females.

Table 4. Paraplegics, Frankel Grades ABC

Attained Age	Exposure, Person-Years (E)	No. Deaths		Mortality Ratio, % ($100\ d/d'$)	Mean Annual Rate per 1000		
		Observed (d)	Expected* (d')		Observed (q)	Expected† (q')	Excess ($q - q'$)
10	500	2	0.26	773	4.00	0.52	3.48
15	1677	10	1.64	610	5.96	0.98	4.99
20	7048	26	9.70	268	3.69	1.38	2.31
25	10,430	46	16.36	281	4.41	1.57	2.84
30	11,256	76	22.45	339	6.75	1.99	4.76
35	9589	90	24.53	367	9.39	2.56	6.83
40	6820	75	22.12	339	11.00	3.24	7.75
45	4623	62	20.34	305	13.41	4.40	9.01
50	3058	49	20.33	241	16.02	6.65	9.37
55	2165	38	22.80	167	17.55	10.53	7.02
60	1577	50	25.99	192	31.71	16.48	15.22
65	1110	47	27.53	171	42.34	24.81	17.54
70	607	42	22.08	190	69.19	36.38	32.81
75	294	27	16.14	167	91.84	54.90	36.94
80	104	13	8.77	148	125.00	84.35	40.65
All	60,858	653	261.04	250	10.73	4.29	6.44

* Expected number based on 1992 US Life Table rates for males and females.

Table 5. Frankel Grade D

Attained Age	Exposure, Person-Years (E)	No. Deaths		Mortality Ratio, % ($100\ d/d'$)	Mean Annual Rate per 1000		
		Observed (d)	Expected* (d')		Observed (q)	Expected* (q')	Excess ($q - q'$)
10	151	0	0.07	0	0.00	0.50	−0.50
15	1108	4	1.10	364	3.61	0.99	2.62
20	4419	12	6.09	197	2.72	1.38	1.34
25	6511	14	10.26	136	2.15	1.58	0.57
30	6776	37	13.47	275	5.46	1.99	3.47
35	5831	24	14.86	161	4.12	2.55	1.57
40	4380	28	14.21	197	6.39	3.24	3.15
45	3259	30	14.37	209	9.21	4.41	4.79
50	2575	31	17.29	179	12.04	6.72	5.32
55	2113	44	22.62	195	20.82	10.70	10.12
60	1709	39	28.76	136	22.82	16.83	5.99
65	1351	44	34.39	128	32.57	25.46	7.11
70	867	55	32.19	171	63.44	37.13	26.30
75	442	38	23.99	158	85.97	54.27	31.71
80	245	17	20.87	81	69.39	85.20	−15.81
All	41,737	417	254.56	164	9.99	6.10	3.89

* Expected number based on 1992 US Life Table rates for males and females.

Table 6. Life Expectancy, Additional Years

Attained Age	C1–C4 ABC*	C5–C8 ABC†	Paraplegic ABC‡	Grade D§	General Population‖
10	36.49	48.84	52.30	57.89	64.27
15	37.31	44.01	48.30	53.10	59.47
20	33.79	39.72	44.69	49.02	54.78
25	30.62	35.57	40.48	44.66	50.14
30	26.78	31.55	36.32	40.11	45.51
35	23.44	27.64	32.48	36.15	40.93
40	20.31	24.24	28.92	31.85	36.42
45	17.79	20.79	25.41	27.80	31.96
50	15.47	17.89	21.99	23.98	27.62
55	13.43	15.13	18.62	20.31	23.46
60	11.46	12.15	15.09	17.26	19.59
65	9.04	9.56	12.25	14.04	16.07
70	7.13	7.49	9.54	11.07	12.90
75	6.14	6.64	7.49	9.30	10.06
80	6.48	5.52	5.48	8.04	7.57

* Basis: Mortality rates from Table 2.
† Basis: Mortality rates from Table 3.
‡ Basis: Mortality rates from Table 4.
§ Basis: Mortality rates from Table 5.
‖ Basis: 1992 US Life Table rates for males and females.

rather than modeled ones. Both reversals occur at ages where the sample sizes are very small, and this may account for the irregularities.

The life-table analysis represented in Table 6 may be sufficient for an individual who is several years postinjury and is categorized simply by neurological-Frankel group. For medico-legal purposes, however, it will usually be necessary to take more characteristics into account, such as the individual's ventilator dependence,[12] ethnicity, sex, and functional skills. There will seldom be enough subjects available that match the individual, and some form of statistical modeling will be needed. This will be the case particularly when some of the characteristics are time varying, such as functional level or ventilator dependence. The modeling process will have 2 components: a method for assessing the subject's mortality risk over the short term (such as the observed study period) and a method of projecting the mortality rates over the remaining life span. We hope to report on these issues elsewhere.

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