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ORIGINAL ARTICLE

Long-term survival after traumatic spinal cord injury: a 70-year British study

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Study design: Retrospective and prospective observational.
Objectives: Analyse long-term survival after traumatic spinal cord injury (SCI) in Great Britain over the 70-year study period, identify mortality risk factors and estimate current life expectancy.
Setting: Two spinal centres in Great Britain.
Methods: The sample consisted of patients with traumatic SCI injured 1943–2010 who survived the first year post-injury, had residual neurological deficit on discharge and were British residents. Life expectancy and trends over time were estimated by neurological grouping, age and gender, using logistic regression of person-years of follow-up combined with standard life table calculations.
Results: For the 5483 cases of traumatic SCI the mean age at injury was 35.1 years, 79.7% were male, 31.1% had tetraplegia AIS/Frankel ABC, 41.2% paraplegia ABC,and 27.7% functionally incomplete lesion (all Ds). On 31 December 2014, 54% were still alive, 42.3% had died and 3.7% were lost to follow-up. Estimated life expectancies improved significantly between the 1950s and 1980s, plateaued during the next two decades, before slightly improving again since 2010. The estimated current life expectancy, compared with the general British population, ranged from 18.1 to 88.4% depending on the ventilator dependency, level and completeness of injury, age and gender.
Conclusions: Life expectancy after SCI improved significantly between the 1950s and 1980s, plateaued during the 1990s and 2000s, before slightly improving again since 2010, but still remains well below that of the general British population.
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INTRODUCTION

An up-to-date knowledge of life expectancy has a huge potential impact on quality of health and social care services for people with spinal cord injury (SCI) in terms of planning necessary provisions for life-long care. In everyday practice, estimated life expectancy is used for creating personalised care packages for individuals with SCI and for calculating life-long costs of SCI care. Changing trends in life expectancy are among the main outcome measures for assessing the quality of healthcare, its improvement over time, its deficiencies and areas for possible further improvement.

Life expectancy of people with traumatic SCI, though shorter compared with the general population, has been improving dramatically since the Second World War.[1–7] Medical advances in the second half of the twentieth century, improved emergency medical services and opening of specialised spinal injury centres have significantly improved both the immediate and long-term survival following SCI. However, the latest reports from the USA suggest that this improvement in long-term survival is now slowing down and even showing a reversed trend.[8–10] The only British study, by Frankel *et al.*,[1] included persons injured between 1943 and 1990 and analysed their long-term survival up to 1993. The current study is a continuation of that original survival study. In this study, newly admitted cases since 1990 up to the end of 2010 were added to the original sample. The survival status for the entire updated sample was followed up to the end of 2014.

The aim of this paper was to analyse long-term survival after traumatic SCI in Great Britain over the 70-year study period, identify possible risk factors for mortality and estimate current life expectancy for people with traumatic SCI.

Setting

The study took place at the two oldest British spinal centres: the National Spinal Injuries Centre (NSIC) at Stoke Mandeville Hospital, Buckinghamshire Healthcare NHS Trust and the North West Regional Spinal Injuries Centre (NWRSIC) at Southport Hospital, Southport and Ormskirk NHS Trust.

MATERIALS AND METHODS

Study design

Retrospective medical records data review and retrospective and prospective mortality data collection.

Sample

The sample consisted of patients with traumatic SCI admitted to Stoke Mandeville and Southport spinal centres who were injured between 1943 and

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2010, survived the first year post-injury, had residual neurological deficit on discharge and were British residents.

The sample was identified through a thorough medical record review at the two spinal centres, with records dating back to 1944 at Stoke Mandeville and 1948 in Southport.

A detailed explanation of the original sample identification procedure can be found in the original study manuscript.[1] For the newly added cases, most of the original study inclusion criteria were kept, as listed above. The original criterion of admission to a spinal centre within one year of injury was abandoned, as long as patients were treated at one of the two participating spinal centres. Also abandoned was the criterion of the residence in the 17 county catchment area of the two centres, because the catchment areas have changed over time; instead, the inclusion criterion was residence in England and Wales, where all the past and present catchment areas for the two centres were.

Data collection

Patient demographic and injury information was collected retrospectively from the medical records at the two spinal centres.

Survival status up to and including 31 December 2014, and death certificates for the deceased, were supplied by the Medical Research Information Service, Health and Social Care Information Centre (HSCIC), on behalf of the United Kingdom (UK) Office for National Statistics. Data exchange was done through a secure HSCIC Data Exchange Service. The UK Office for National Statistics also produced national life tables for the general population of England and Wales by age and gender.

Data analysis

Data analyses were performed on an anonymised database using Statistical Package for the Social Sciences (SPSS) version 17 (SPSS, Chicago, IL, USA), SPSS version 22 (International Business Machines (IBM) Corporation, Armonk, NY, USA) and Statistical Analysis System (SAS) version 9.3 (SAS Institute, Cary, NC, USA) programmes.

Descriptive statistics were used for presenting the sample characteristics.

For analysis purposes the sample was divided into five injury severity subgroups, based on the International Standards for Neurological Classification of Spinal Cord injury (ISNCSCI).[11] In cases where a complete neurological examination according to the ISNCSCI was not performed and/or recorded (most cases admitted before the 1990s), the classification was done according to the Frankel classification.[12] The five groups were: those with a ventilator-dependent SCI regardless of the level or grade of injury; those with a high tetraplegia C1–C4 and American Spinal Injuries Association (ASIA) Impairment Scale (AIS) or Frankel grade A, B or C (C1–4 ABC); those with a low tetraplegia C5–C8 and AIS/Frankel grade A, B or C (C5–8 ABC); those with a paraplegia and AIS/Frankel grade A, B or C (para ABC); and those with a very incomplete SCI of AIS/Frankel grade D regardless of the level of injury (all Ds).

Cumulative survival stratified by neurologic category was assessed by using standard life table techniques.[13,14] On the basis of the results of the logistic regression analysis described below, only persons injured since 1 January 1980 were included in this analysis, so that the results would more reasonably reflect current survival expectations.

Data were analysed with each year of follow-up for each person (person-year) being treated as a separate observation. Thus, a person who was followed for 5 years and died during the fifth year would contribute five observations to the data set. The person in this example would be considered as alive at the end of each of the first four observations and deceased for the fifth observation. Logistic regression was then used to determine mortality odds ratios (OR) and 95% confidence intervals for selected risk factors, as well as the probability of dying in any given year based on the presence or absence of each risk factor. Those factors included in the model were current age, year post-injury and calendar year of each follow-up year of observation, as well as gender and neurological group. Mortality OR of 1 (OR = 1) denoted the reference group, whereas OR < 1 meant lower odds of dying and OR > 1 meant greater odds of dying relative to the reference group. Confidence intervals not containing the '0' value, as well as *P*-value <0.05, indicated statistical significance. Age-specific probabilities of dying each year derived from the model were then used to create life tables from which life expectancy was calculated using standard statistical methods. Current life expectancies after SCI were based on the logistic regression model coefficient for the 2010–2014 calendar time period. Life expectancy estimates for prior decades were based on the logistic regression coefficient for that decade, to assess trends in life expectancy over time. This method of analysis has been described in detail elsewhere.[15]

The percentage of normal life expectancy was calculated by comparison to general population period life tables for England and Wales for the concomitant calendar period. The current life expectancy after SCI was compared with the latest available general population life tables (England and Wales 2012–2014 period life tables). Unless stated otherwise, study periods throughout the manuscript referred to the study observation period (calendar years of follow-up) and not the calendar years of injury.

Statement of ethics

The study was approved by Berkshire Research Ethics Committee (REC), REC reference number 11/H0505/1.

Table 1 Demographic and injury characteristics by SCI period

	Decade of injury			
	1943–1969 (n = 1272)	*1970–1989 (n = 1876)*	*1990–2010 (n = 2335)*	*Combined (n = 5483)*
Age at injury (years)				
Mean	32.86	32.32	38.61	35.12
Range	1.34–85.65	0.57–87.03	0.5–90.99	0.5–90.99
Median	29.10	27.34	35.16	30.68
Age at injury group (%)				
0–29	52.7	56.7	39.6	48.5
30–59	41.4	35.1	45.7	41.1
60+	5.9	8.2	14.8	10.4
Gender (%)				
Male	85.5	78	77.9	79.7
Female	14.5	22	22.1	20.3
Neurologic group (%)				
Ventilated	—	0.5	2.7	1.4
Tetra C1–4 ABC	1.4	5.5	9.7	6.3
Tetra C5–8 ABC	17.7	29.5	21.6	23.4
Para ABC	50.8	40.1	36.9	41.2
All Ds	30.1	24.4	29.1	27.7
Neurologic group 2 (%)				
Tetra complete (A)	13.1	22.5	21.1	19.8
Tetra incomplete (BCD)	21	27.2	30.6	27.2
Para complete (A)	46.6	33.9	29.8	35.1
Para incomplete (BCD)	19.3	16.4	18.5	18
Aetiology (%)				
Traffic accident	46.9	49.6	43.1	46.1
Fall	30.5	29.4	33.2	31.3
Sport	6.4	13.2	14.8	12.3
Hit by object	10.8	4.9	2.1	5.1
Violence	4.9	2.4	4	3.7
Other aetiology	0.5	0.5	2.8	1.5
Survival status (%) on 31.12.2014				
Alive	15.6	51.9	76.5	54
Dead	76.6	43	23.2	42.3
Lost	7.8	5.1	0.3	3.7

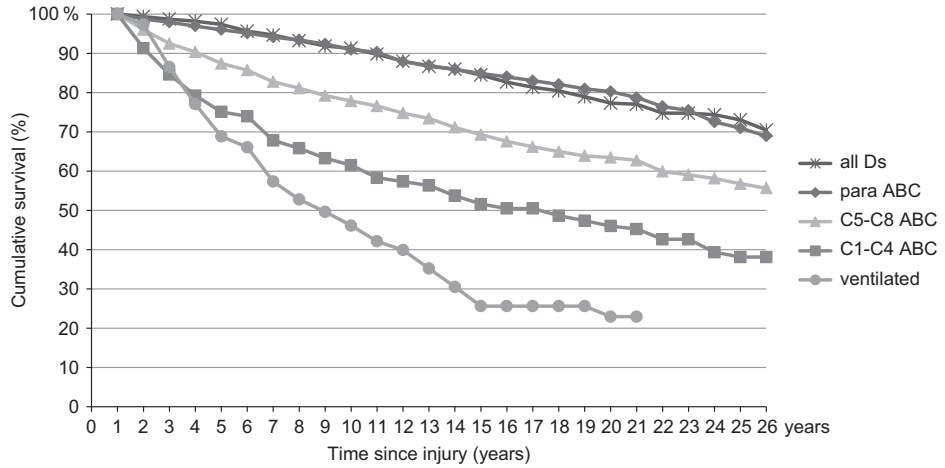

Figure 1 Cumulative 25 year survival curve versus time since injury for 1980–2014 study period by five neurological groups. A full color version of this figure is available at the *Spinal Cord* journal online.

We certify that all applicable institutional and governmental regulations concerning the ethical use of patient identifiable data were followed during the course of this research.

RESULTS

Sample characteristics

The total sample included 5483 persons with traumatic SCI—the 3179 from the original survival study[1] and the 2304 added in the current follow-up study. The mean age at injury for the entire updated sample was 35.12 years (range: 0.5–90.99, median 30.68), 79.7% were male, 1.4% had a ventilator-dependent tetraplegia, 6.3% C1–C4 tetraplegia AIS/Frankel ABC, 23.4% C5–C8 tetraplegia ABC, 41.2% paraplegia ABC and 27.7% incomplete lesion (all Ds).

Demographic and injury characteristics by decade of injury and for the entire 70-year study period are shown in Table 1. After a slight decrease in the 1970s and 1980s, the average age at injury increased in the last 20-year study period. The percentage of newly injured at age 60 and older increased from 5.9% in the first three decades to 14.8% of all newly injured in the last two decades. The proportion of females also increased, mainly between the early and middle study period, as did the proportion of persons with functionally complete tetraplegia (ventilated, tetra C1–4 ABC and tetra C5–8 ABC combined). Looking at the alternative neurological grouping, proportion of both tetra complete (A) and tetra incomplete (BCD) groups increased over time. The leading cause of injury throughout the study were road traffic accidents, but their proportion decreased in the latter study decades, whereas the proportion of injuries due to falls and sport increased. Road traffic accidents were the most frequent cause in the young and middle aged; 51.9% of all injuries in the under 30-year-old group, 42% in the 30–59-year-old group, and only 16.1% in the 60+-years-old group. At the same time, in the 60+-years-old group, 70.5% of all injuries were due to fall, compared to 34.2% in the 30–59 group and 17.8% in under 30 year olds. Sport injuries, on the other hand, represented 20.8% of all injuries in the youngest age group, 13.2% in the 30–59-year-old group and only 5.1% in the oldest age group. Among other aetiologies, a small, but rising, number of iatrogenic injuries was noted in the last two decades, mainly complications of spinal and aortic surgery.

On 31 December 2014, there were 2958 persons (54% of the sample) still alive, 2322 (42.3%) had died and 203 (3.7%) were lost to follow-up (usually due to not registering with the local medical and social care services, and moving abroad).

Cumulative survival

Cumulative 25 year survival from the first anniversary of injury for persons injured since 01 January 1980 is presented by neurological grouping in Figure 1. Overall survival differences for the five neurological groups were statistically significant ($P<0.0001$), with 25 year survival of 70.44% for persons with AIS/Frankel grade D injuries at any level, 68.91% for persons with paraplegia ABC, 55.66% for persons with C5–C8 tetraplegia ABC and 38.1% for persons with C1–C4 tetraplegia ABC, and with differences between all Ds and para ABC groups only becoming apparent more than 15 years post injury.

For ventilator-dependent persons, 20-year survival was 22.93%, after which sample size was too small for reliable estimation.

Mortality risk factors

Gender, current age, time since injury, injury level and AIS/Frankel grade, ventilator dependency and study period were all strong predictors of mortality (Table 2). Long-term survival has been improving continuously since the 1940s and statistically significantly improving since the 1950s. Relative to the mortality OR of 1 for 1944–49, the mortality OR for the 2010–2014 period was 0.17; $P<0.01$, implying an 83% reduction in the annual odds of dying, all other things being equal.

However, this improvement slowed down over time, particularly since the 1980s.

Relative to the 1980s, long-term survival plateaued during the 1990 and 2000 decades (relative to OR = 1 for 1980–1989, OR = 0.91 for 1990–1999 and OR = 0.90 for 2000–2009; both ns), before slightly improving again since 2010 (relative to OR = 1 for 1980–1989, mortality OR = 0.80 for 2010–2014; $P<0.01$).

Estimated life expectancy

Using the logistic regression calculation method, with gender, current age, ventilator dependency, level and grade of injury as mortality risk factors, the estimated current life expectancy by gender is presented in Tables 3a and 3b. Compared with the age and gender matched members of the general population (period life tables for England and Wales 2012–2014), the estimated current life expectancy for first year SCI survivors ranged from 18.1% of that of the general population for

Table 2 Mortality odds ratios with 95% confidence intervals (CI) for risk factors: gender, current age, time since injury, neurological grouping and study period (decade of observation)

Risk factor	*Coefficient*	*Odds ratio*	*95% CI lower limit*	*95% CI upper limit*	*P-value*
Intercept	−5.0241				
Gender					
Female	0	1			
Male	0.2352	1.27	1.13	1.41	<0.0001
Current age					
Age 0–24	0	1			
Age 25–29	0.1909	1.21	0.80	1.83	0.3621
Age 30–34	0.4258	1.53	1.04	2.25	0.0303
Age 35–39	0.9771	2.66	1.87	3.78	<0.0001
Age 40–44	1.2132	3.36	2.38	4.75	<0.0001
Age 45–49	1.6005	4.96	3.40	6.94	<0.0001
Age 50–54	1.8384	6.29	4.50	8.79	<0.0001
Age 55–59	2.3001	9.98	7.18	13.85	<0.0001
Age 60–64	2.6498	14.15	10.20	19.63	<0.0001
Age 65–69	3.0584	21.29	15.36	29.51	<0.0001
Age 70–74	3.4510	31.53	22.65	43.89	<0.0001
Age 75–79	3.7926	44.37	31.48	62.55	<0.0001
Age 80–84	4.2470	69.90	48.58	100.57	<0.0001
Age 85–89	4.3601	78.27	51.27	119.50	<0.0001
Age 90+	4.8012	121.65	70.46	210.04	<0.0001
Time since injury					
Post-injury year 2	0.4126	1.51	1.26	1.82	<0.0001
Post-injury year 3–4	0.2391	1.27	1.09	1.48	0.0019
Post-injury year 5+	0	1			
Neurologic group					
Ventilator-dependent	2.0114	7.47	5.37	10.40	<0.0001
C1–4 Frankel/AIS A, B or C	1.3474	3.85	3.22	4.58	<0.0001
C5–8 Frankel/AIS A, B or C	0.9787	2.66	2.35	3.01	<0.0001
T1–S3 Frankel/AIS A, B or C	0.4371	1.55	1.39	1.73	<0.0001
Frankel/AIS D	0	1			
Study period					
1944–49	0	1			
1950–59	−0.4604	0.63	0.31	1.31	0.2142
1960–69	−1.0295	0.36	0.18	0.72	0.0037
1970–79	−1.1673	0.31	0.16	0.62	0.0009
1980–89	−1.5024	0.22	0.11	0.44	<0.0001
1990–99	−1.6122	0.20	0.10	0.40	<0.0001
2000–09	−1.6322	0.20	0.10	0.39	<0.0001
2010–14	−1.7664	0.17	0.09	0.34	<0.0001

Abbreviations: AIS, American Spinal Injury Association (ASIA) Impairment Scale; CI, confidence interval.

an 80-year-old ventilator-dependent male to 88.4% for a 10-year-old male with a functionally incomplete SCI (AIS/Frankel grade D of any level).

Table 4 illustrates trends in life expectancy by decades over the study period using the example of a 20-year-old male who survived the first year post-injury. Life expectancy after traumatic SCI was improving at a faster rate than that of the general population in England and Wales for the same time periods up to the 1990s for AIS/Frankel D, para ABC and tetra C5-8 ABC neuro groups and up to the 2000s for C1–4 ABC and ventilated neuro groups, but at a slower rate since then.

DISCUSSION

The aims of this paper were to analyse long-term survival after traumatic SCI in Great Britain over the 70-year study period, identify possible risk factors for mortality and estimate current life expectancy for people with traumatic SCI.

Mortality risk factors, identified in our original study,[1] and in other similar studies,[2,3,5,7–10,16–18] were confirmed in this study, and included gender, current age, time since injury, neurological grouping and study period (Table 2).

Controlling for all the other risk factors in the model, males had a 27% higher mortality risk than females, the risk of dying increased with age, significantly so after the age of 30, and with higher level and completeness of SCI. On the other hand, mortality risk decreased with time post-injury and over the study observation period.

First year post-injury survival was not included in this study for several reasons: due to differences in admission policies over the study period the time since injury on admission varied, which means that an unknown percentage of early deaths would have occurred in referring hospitals. Also, deaths at the scene of accident and during transport to hospital would have been unknown to us. It is generally agreed that the first few years post injury carry a higher mortality risk. In the earlier studies, different points in time after SCI were used to distinguish between early (acute) and long-term survival—1 year,[1,5,7,8] 18 months[19] and 2 years.[9,10] We used the 1 year cut-off point, as in our original study of long-term survival.[1] Similar to the Australian and American SCI Model System reports,[5,7,8–10] we found that increased mortality risk continues into second year post injury (OR = 1.46) and even into the third and fourth year (OR = 1.26) and only stabilises after year five post-injury (OR = 1, Table 2). Preliminary analysis had shown very similar mortality ORs for post injury years 3 and 4, which is why they were combined in one group for analysis purposes. Preliminary analysis had also shown no significant difference in mortality odds after year 5, assuming comparable current age and calendar year, which is why 5+ was the last post injury year category.

Different neurological groupings have been suggested in the past for SCI survival analysis. Coll *et al.*[20] suggested that persons with lower level functionally complete paraplegia (AIS/Frankel grade ABC) may be more similar to those with functionally incomplete (AIS/Frankel grade D) tetraplegia in this respect, whereas persons with high level tetraplegia and AIS/Frankel grade B and C are more similar to those with high level paraplegia and AIS/Frankel grade A. Coll *et al.*,[20] Strauss *et al.*[9] and Shavelle *et al.*[10] all agree that AIS/Frankel grade A lesion carries a higher mortality risk compared to other AIS/Frankel grades, particularly in people with tetraplegia. For consistency, we kept to our original study grouping (high tetra ABC, low tetra ABC, para ABC and all Ds) and just added a ventilator-dependent group, which included either full-time or part-time mechanical ventilation, as long as it was permanent, and phrenic nerve stimulators. DeVivo and Ivie,[21] Shavelle *et al.*,[22] Watt *et al.*[23] and Hatton *et al.*[24] analysed ventilator-dependent cases separately. We included ventilator-dependent cases in our updated sample, and this group had significantly higher mortality ORs—seven and a half times higher than the Frankel/AIS D group—and correspondingly shorter life expectancy. At the same time the non-ventilator-dependent high tetra group (C1–4 ABC) had the OR = 3.85 and the C5–8 ABC group

Table 3a Estimated current life expectancy for male first year survivors by age and neurological grouping, calculated using the logistic regression method, expressed in remaining years of life and as percentage of the mean life expectancy in the general population (England and Wales 2012–2014 period life tables)

	General population	*AIS/Frankel D*		*Para ABC*		*C5–8 ABC*		*C1–4 ABC*		*Ventilated*	
	Mean	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*
	Years	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*
					MALE life expectancy						
Current age											
10	69.7	61.6	88.4	55.8	80.1	48.4	69.4	43.4	62.3	34.3	49.2
15	64.8	57	88	51.4	79.3	44.3	68.4	39.5	61	31	47.8
20	59.9	52.4	87.5	47	78.5	40.1	66.9	35.5	59.3	27.7	46.2
25	55	47.8	86.9	42.5	77.3	35.8	65.1	31.4	57.1	24	43.6
30	50.2	43.1	85.9	38	75.7	31.6	62.9	27.4	54.6	20.4	40.6
35	45.3	38.5	85	33.5	74	27.3	60.3	23.4	51.7	16.9	37.3
40	40.6	34.2	84.2	29.4	72.4	23.6	58.1	19.9	49	14.1	34.7
45	35.9	29.9	83.3	25.4	70.8	19.9	55.4	16.6	46.2	11.3	31.5
50	31.3	25.9	82.7	21.7	69.3	16.7	53.4	13.6	43.5	9.1	29.1
55	26.9	21.9	81.4	18	66.9	13.4	49.8	10.7	39.8	6.8	25.3
60	22.6	18.3	81	14.8	65.5	10.7	47.3	8.4	37.2	5.2	23
65	18.5	14.9	80.5	11.8	63.8	8.2	44.3	6.3	34.1	3.8	20.5
70	14.7	11.9	81	9.3	63.3	6.3	42.9	4.7	32	2.8	19
75	11.3	9.3	82.3	7.2	63.7	4.8	42.5	3.5	31	2.1	18.6
80	8.3	7	84.3	5.5	66.3	3.5	42.2	2.5	30.1	1.5	18.1

Abbreviation: AIS, American Spinal Injury Association (ASIA) Impairment Scale.

Table 3b Estimated current life expectancy for female first year survivors by age and neurological grouping, calculated using the logistic regression method, expressed in remaining years of life and as percentage of the mean life expectancy in the general population (England and Wales 2012–2014 period life tables)

	General population	*AIS/Frankel D*		*Para ABC*		*C5–8 ABC*		*C1–4 ABC*		*Ventilated*	
	Mean	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*
	Years	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*
					FEMALE life expectancy						
Current age											
10	73.4	64.7	88.1	59.1	80.5	51.6	70.3	46.6	63.5	37.5	51.1
15	68.4	60	87.7	54.6	79.8	47.4	69.3	42.5	62.1	34	49.7
20	63.5	55.4	87.2	50	78.7	43.1	67.9	38.4	60.5	30.4	47.9
25	58.5	50.7	86.7	45.4	77.6	38.7	66.2	34.2	58.5	26.6	45.5
30	53.6	46	85.8	40.9	76.3	34.3	64	30	56	22.8	42.5
35	48.7	41.3	84.8	36.3	74.5	30	61.6	25.9	53.2	19.1	39.2
40	43.9	36.9	84.1	32.1	73.1	26.1	59.5	22.2	50.6	16	36.4
45	39.1	32.5	83.1	27.9	71.4	22.2	56.8	18.7	47.8	13.1	33.5
50	34.4	28.3	82.3	24.1	70.1	18.8	54.7	15.5	45.1	10.6	30.8
55	29.8	24.2	81.2	20.2	67.8	15.3	51.3	12.4	41.6	8.1	27.2
60	25.3	20.4	80.6	16.8	66.4	12.3	48.6	9.8	38.7	6.2	24.5
65	21	16.8	80	13.6	64.8	9.7	46.2	7.5	35.7	4.5	21.4
70	16.9	13.6	80.5	10.9	64.5	7.5	44.4	5.7	33.7	3.3	19.5
75	13.1	10.8	82.4	8.6	65.6	5.7	43.5	4.3	32.8	2.5	19.1
80	9.7	8.2	84.5	6.5	67	4.3	44.3	3.1	32	1.8	18.6

Abbreviation: AIS, American Spinal Injury Association (ASIA) Impairment Scale.

Table 4 Trends in life expectancy by study decades for a 20-year-old male first year survivor, expressed in remaining years of life and as percentage of the mean life expectancy in the general population for England and Wales for the relevant time period (decade of observation)

	General population	*AIS/Frankel D*		*Para ABC*		*C5–8 ABC*		*C1–4 ABC*		*Ventilated*	
	Mean	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*	*Mean*	*% General population*
	Years	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*	*Years*	*%*
					20-year-old male life expectancy						
Study period											
1943–1949	48.8	30.5	62.5	25.5	52.3	19.7	40.4	16.2	33.2	10.7	21.9
1950–1959	50	36	72	30.8	61.6	24.6	49.2	20.7	41.4	14.4	28.8
1960–1969	50.8	43.2	85	37.7	74.2	31.1	61.2	26.8	52.8	19.7	38.8
1970–1979	51.7	44.9	86.8	39.4	76.2	32.7	63.2	28.5	55.1	21.1	40.8
1980–1989	53.2	49	92.1	43.6	82	36.8	69.2	32.3	60.7	24.7	46.4
1990–1999	55.2	50.3	91.1	45	81.5	38.2	69.2	33.7	61.1	25.9	46.9
2000–2009	57.6	50.8	88.2	45.3	78.6	38.4	66.7	33.9	58.9	26.1	45.3
2010–2014	59.8	52.4	87.6	47	78.6	40.1	67.1	35.5	59.4	27.7	46.3

Abbreviation: AIS, American Spinal Injury Association (ASIA) Impairment Scale.

OR = 2.66 relative to the Frankel/AIS D group (OR = 1), whereas the paraplegia ABC group had only 55% higher mortality odds (OR = 1.55) than the reference all Ds group. It is worth keeping in mind that, due to combining Frankel/AIS grades A, B and C into one group for mortality analyses, the calculated mortality odds ratios for 'functionally complete' groups represent a slight underestimate for Frankel/AIS A and possibly B grades, and a slight overestimate for grade C cases. Correspondingly, life expectancies in Tables 3a and 3b would be slightly overestimated for Frankel/AIS grade A and possibly B, and underestimated for Frankel/AIS grade C cases.

One of the main aims of this paper was to identify any mortality trends over the 70-year study period. The results show that the improvement in long-term survival in first year survivors, which started in the 1950s, continued throughout the study, but at a slower rate since the 1980s (Table 2). Compared with the improvement in life expectancy in the general population in England and Wales for the same 70-year period (1944–2014), the improvement in persons with SCI was greater in the 1950s, 1960s, 1970s and 1980s, peaked between the 1990s and 2000s, then continued improving at a slower rate than that of the general population, as shown in the example in Table 4. In the first 5 years of this decade (2010–2014) the improvement in post SCI survival was still lagging behind that of the general population, but the gap in survival improvement seemed to be narrowing in the most severely impaired groups (ventilated, C1–C4 ABC and C5–8 ABC).

The findings of slower improvement in long-term survival in recent study decades, and of the increasing gap in improvement between persons with SCI and the general population, are consistent with the USA SCI Model Systems latest reports.[9,10] In the USA, the age-adjusted mortality rates for heart disease, cancer, pulmonary embolus and urinary system diseases have declined for persons with SCI just as they have for the general population. However, there has not been any recent progress in the age-adjusted mortality rates for septicaemia and respiratory diseases (the two leading causes of death following SCI), whereas age-adjusted mortality rates for endocrine, nutritional, and metabolic disorders, accidents, mental disorders and homicides have actually increased.[25] Indeed, we are currently analysing causes of death after SCI in our sample and hope that the results will provide some new information. Any other possible contributing factors would require additional research, to fully understand the problem.

Finally, the study provided estimated current life expectancy in first year post-injury survivors in England and Wales, based on the latest available general population and traumatic SCI data (Tables 3a and 3b). It is worth noting that the general population tables used for comparison were period life tables with age-specific death rates for 2012–2014, which make no allowance for any actual or projected changes in mortality in the future.

The original study by Frankel *et al.*[1] used a then-available DeVivo *et al.*[5] American publication for comparison and found the results comparable. Both studies included first year SCI survivors and used standardised mortality ratios (SMRs) for calculating life expectancy. The last USA SCI Model System publication using the same methodology was DeVivo *et al.*[8] Since then two USA SCI Model System updates have been published, Strauss *et al.*[9] and Shavelle *et al.*,[10] both using a similar logistic regression method as in our current study, but with more predictor variables, slightly different neurological groupings, and including only second year SCI survivors. Comparing their results to the current study, predicted life expectancies were quite close and differed by a few years only, with British results being slightly higher for comparable groups (para ABC and all Ds) in spite of including second year survivors in our sample. Other recently published findings are reported in the Australian survival after SCI study by Middleton *et al.*[7] Life expectancies in their study, given as a percentage of the general Australian population life expectancy, were much higher than those in either the USA or British studies. However, unlike the latest USA and British studies, the Australian study used the previously mentioned SMR method, so the results cannot be easily compared.

In addition, this study provided some new information about changes in aetiology and in demographic and injury characteristics of the newly injured traumatic SCI in Britain (Table 1). Although some of the changes were likely due to the two centres' admission criteria and bed availability, the findings were similar to others' published results.[7,26–28] As in the reports from other developed countries, the leading causes of traumatic SCI were road traffic accidents, but their proportion decreased in the latter study decades, as did the proportion

of injuries by falling objects, most of which were industrial accidents. At the same time, the proportion of injuries due to falls and sport increased—falls in older and sport in younger and middle age groups. In the last 20-year study period, the average age at injury increased, mean to 38.61 years and median to 35.16 years, and the percentage of newly injured at age 60 and older more than doubled, to 14.8% of all newly injured in the last two study decades. The proportion of females also increased, mainly between the early and middle study period, from 14.5 to 22.1%, as did the proportion of persons with functionally complete tetraplegia, from 19.1% in the early decades to 35.55% in the middle study period, to 34 % in the last 20 years. A particularly high increase was noted for functionally complete high tetraplegia—from 1.4% to 6 to 12.4% for the ventilated and tetra C1–4 ABC groups combined. It is worth noting that the 'functionally complete' grouping, used for survival analyses, included complete (Frankel/AIS grade A) SCI cases, as well as Frankel/AIS grade B and C cases. If the complete (A) injuries were separated from all the incomplete ones (B,C,D) as in 'Neurologic group 2′ in Table 1, then the most common injury type in the early decades would be complete paraplegia (46.6%) and in the last 20 years incomplete tetraplegia (30.6%). Similar trends were reported in several recent publications.[7,26–29]

Limitations

Limitations of this study include a lack of information about possible other mortality risk factors, such as associated medical conditions, family history, lifestyle, as well as numerous psychosocial factors associated lately with mortality after SCI.[30–32]

Information on ventilator dependency was not included in the original survival study[1] for patients injured before 1990, because of very small numbers, but was added to the current data set from the old medical records (all newly added cases injured since 1990 included ventilator dependency information). For some cases with incomplete information about ventilator dependency, we relied on the memory of the treating physicians, so some of the information may have been biased by selective memory of longer surviving ventilator-dependent patients. Previous studies of ventilator-dependent patients in the USA found lower life expectancies than were found in this study.[21,22] At the same time, life expectancy in the C1–4 ABC group was lower in our study than in the USA studies. This could mean that some of the ventilator-dependent cases from earlier decades in our study were included in the C1–4 ABC group.

Persons who were lost to follow-up were slightly older and as a result disproportionately likely to have died. This may have resulted in a small bias toward overestimating life expectancy.

The sample size for the latest decade (2010–2014) was smaller than for the previous decades, so the recent improvement in survival should be interpreted with caution until confirmed.

Strengths

The results of this study could be generalised and used in the whole country, as the study sample can be considered representative of the British SCI population. The catchment areas of the two participating centres cover about a third of the British population and include the South-East and the North-West of the country. The majority of patients with neurological deficit due to spinal injury are treated in spinal centres.[33] All British spinal centres are part of the National Health Service (NHS), which is a publicly funded health service, free at the point of delivery to all British residents.

CONCLUSIONS

Life expectancy after traumatic SCI remains significantly below that of the general population in England and Wales, and is dependent on gender, current age, time since injury, ventilator dependency, level and completeness of injury, and study period. After improving at a faster rate than that of the general population from the 1950s up to the 1990s, and a period of stability in the 1990s and 2000s, it has been improving again since 2010, but at a slower rate than that of the general population. The estimated current life expectancy, compared to that of the general population, ranges from 18.1 to 88.4% depending on the neurological grouping, current age and gender.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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