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ORIGINAL ARTICLE

Survival after short- or long-term ventilation after acute spinal cord injury: a single-centre 25-year retrospective study

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Study design: A retrospective review of acute spinal cord injury patients having assisted ventilation on or after admission between 1981 and 2005.
Objective: To assess survival after acute ventilatory support.
Setting: Northwest Regional Spinal Injuries Centre, Southport, England.
Methods: Causes of death were ascertained from the Office of National Statistics. Kaplan–Meier analysis of survival was calculated according to ventilator-wean status at discharge. Risk factors were obtained by Cox regression analysis.
Results: Over 50% of deaths in weaned and ventilated patients were respiratory in origin. The mean survival of weaned patients in the age group 31–45 was 19.3 compared with 10.5 years for ventilated patients ($P=0.047$). Those under 30 survived a further 22.1 and 18.4 years ($P=0.31$), while those over 45 lived for 11.0 and 8.3 years ($P=0.50$), values for weaned and ventilated patients, respectively. The survival advantage for weaned patients in the middle age group was less evident when the 1-year survivors were compared. The mean survival time of younger patients with diaphragm pacing was 1.8 years longer than those on mechanical ventilation ($P=0.142$). The variables with significant hazard ratios were any comorbidity (3.07); mechanical ventilation on discharge (2.26); and older age at injury, (3.1).
Conclusions: The survival time for patients with high tetraplegia on long-term ventilation compares with other datasets and older patients have a proportionately greater loss in life expectancy. Self-ventilating patients with tetraplegia remain at considerable risk from respiratory death and consideration needs to be given to more effective preventative measures.

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Keywords: spinal cord injury (SCI); tetraplegia; ventilator dependency; ventilator weaning; mortality; survival analysis

Introduction

The underlying cause of respiratory failure, whether progressive or essentially static, in patients having long-term ventilatory support will in itself have a part in determining life expectancy. Over 10 years ago Goldberg expressed the urgent need for more information about clinical outcomes from long-term ventilatory support to inform clinical decision making and justify programme development and public policy.[1]

Though spinal cord injury has not always been differentiated from other conditions in earlier long-term outcome studies, a group of 22 patients with spinal cord injury was found to have the best median survival of 47 months out of a cohort of 293 when followed over 20 years.[2]

In a larger single-centre dataset of tetraplegic persons ventilated after spinal cord injury, incorporating 134 patients over a 10-year period, 35% of hospital survivors were discharged with ventilatory support.[3] The overall survival fell from 90% at the first year post-injury to 33% at 5 years. In contrast, those patients who weaned from the ventilator had a 100% 1-year survival and an 84% 5-year survival. Outcome was better at lower neurological levels for weaned patients, but other influential factors such as age stratification were not considered.

This same dataset would have been included in a number of studies from the National Spinal Cord Injury Statistical Centre, which has collated data from model spinal cord injury centres in the United States and which is thought to capture data on 13% of persons with spinal cord injury in

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the United States. In the analysis of a 20-year dataset, 2%—equivalent to 435 persons—required ventilatory support and survived the first 24 h of injury to be discharged with ventilatory support.[4] In studying the survival from the time of discharge, with 20% of patients having a neurological level of C5 and below, it was acknowledged that a number of patients would have weaned following discharge from the model centres. Nevertheless, the leading cause of death was respiratory in origin in 27.3%.

A subsequent 30-year analysis of adult 1-year survivors discharged with ventilatory support compared outcomes between the 86% with neurology C1–5 AIS A (American Spinal Injury Impairment Scale) and the 14% with better neurology.[5] Among those who survived the first year, the odds ratio of dying was 2.2648 higher in the high-level group than those with lower-level neurology though it is acknowledged that the data collection could not identify those who may have weaned after discharge. Respiratory diseases accounted for 31% of the known causes of death. Even within a whole dataset of 28 239 patients followed since 1973, respiratory deaths were the leading cause in the first year at 28%, though this fell to 18% beyond that time.[6]

An Australian study of 2892 patients looked at survival from the date of the SCI, but it was acknowledged that data from ventilated patients could not be included[7] and causes of death were not compared.

A 50-year-long study of the long-term survival of 3179 patients, who had survived beyond their first year of injury, compared data from the National Spinal Injuries Centre at Stoke Mandeville and the NorthWest Regional Spinal Injuries Centre (NWRSIC) at Southport, England.[8] All C1–4 Frankel A/B/C cases were grouped together, representing 4.2% of the total, but the outcome for the small number of ventilator-dependent persons could not be differentiated. The leading cause of death in this whole cohort was respiratory, which amounted to 34% during the second time period studied. Since the end of that study period, the NWRSIC has continued to treat a large number of patients with respiratory failure and so has an extensive dataset of patients requiring either short- or long-term ventilatory support,[9] some of whom could be weaned even after initial failure in the referring hospital.[10]

The vulnerability of patients with tetraplegia to respiratory failure following respiratory infection is well known and it is not self-evident that mid-level tetraplegic patients have a lower risk of respiratory death than those who remain on ventilatory support. Therefore, the objective of the present study was to compare the long-term survival of patients who were having mechanical ventilation on discharge from a single spinal injury centre with the cohort who had been weaned from mechanical ventilatory support prior to discharge, and to examine the causes of death and contributory factors.

Materials and methods

All patients who had been ventilated during an admission to the NWRSIC between years 1981 to 2005 were known to at least one of the authors (JWHW) and their case records were searched by demographic, diagnostic and outcome data.

Patients were broadly categorized as traumatic if they had sustained spinal cord damage following an injury, or as non-traumatic if the damage had arisen from other causes such as a vascular event, or if the respiratory failure had been due to another disorder such as transverse myelitis or motor neurone disease. Adults and children with traumatic spinal cord injury were included if it was their first admission to the NWRSIC when they had been ventilated. Cases were excluded if they had been ventilated for less than 5 days or if the cause was non-traumatic, which therefore also excluded those with previously established spinal cord damage needing ventilatory support only on a subsequent admission.

The survival status of those who had been lost to follow-up was ascertained from the last known general practitioner. The causes of deaths were requested from the Office of National Statistics (ONS) after their ethical review, and the study also had prior scrutiny by the Local Research Ethics Committee and the hospital Trust Research and Development department.

Because of the wide range of times to discharge of weaned and more especially ventilator-dependent patients, often for non-medical reasons, the survival time was calculated in weeks from the date of initiation of ventilation, whether or not they had died before discharge. The date of ventilation was invariably within a few days of injury and in some cases was before admission to the NWRSIC. Survival times were then re-calculated for those patients who had survived beyond their first year of injury.

After grouping patients according to their wean status at time of discharge, or death if sooner, they were stratified into five subgroups, each straddling 15 years. The numbers in a couple of outlying subgroups, however, were less than 5 each, so the two outer subgroups were then combined to give final age sub-groupings of 0–30, 31–45, and 46 and over.

Motor levels at the time of discharge were ascertained from the case records and classified according to the International Standard Neurological Classification of Spinal Cord Injury with the American Spinal Injury Association Impairment Scale (AIS) best motor level, whichever side was the higher.[11] The motor levels of the majority of the patients were above the C5 level for which the sensory level is not a sufficient guide to the respiratory muscle function. The functional motor level was therefore coded according to the preservation, in ascending order, of diaphragm (C4); trapezius (C3); sternomastoid (C2); or loss of sternomastoid (C1), as tabulated by Somers.[12] In this scheme, the author drew upon seven sources, acknowledging the lack of agreement on innervation of spinal segments at this level.

Co-morbidities were grouped into either none or one of six categories such as respiratory, but the data collection did not allow for adequate analysis of co-existing injuries.

Causes of death were classified according to The International Classification of Diseases (ICD)-10. Data were analysed using SPSS version 17 to obtain descriptive statistics for the major outcome of death or survival according to mode of breathing on discharge, age, gender, neurological classification and scoring, and co-morbidities. Survival times in weeks were calculated by Kaplan–Meier analysis and the results expressed in years, to one decimal place.

The significance of categorical variables was interpreted by Cox regression analysis.

Results

Between January 1981 and December 2005 there were 262 patients having invasive ventilatory support, among whom 189 had had traumatic spinal cord injury and required ventilatory support on their first admission to NWRSIC and whose case records could be found (Figure 1). Motor vehicle accidents (MVAs) accounted for 45%, with sports and falls each contributing just under a quarter of cases, though the incidence of falls was much higher in patients who weaned.

The group discharged with ventilatory support had both a longer delay in admission to the NWRSCI—reflecting referrals of high-level cases from beyond the normal catchment area—as well as a slower discharge process though there was a large spread of times within both groups. The total hospital time from the time of ventilation to discharge was 50.1 weeks for weaned patients compared with 127.3 weeks for those discharged with ventilatory support (Table 1).

There was only one patient discharged on ventilatory support with neurology below C4, the other died while still in hospital (Table 2). The ventilatory status of all patients at the time of discharge remained unchanged subsequently. The finding of ventilated patients with neurological levels below T1 reflected co-existing serious illness from which some such cases died while still on ventilatory support in hospital.

Fifty males were discharged on ventilatory support (mean age 32.1 years) compared with 5 females (33.2 years), and 113 males were ventilator free on discharge (37.6 years) compared with 21 females (48.3 years). There were 79 patients in the 0–30 age subgroup; 46 in the 31–45 age subgroup, and 72 were older than 46 years (Table 3).

The mean survival times were better for the weaned patients compared with the ventilated patients, although this achieved significance only for patients aged 31–45, with values of 19 and 10.5 years, respectively (Table 4a). There is a steady slope in mortality for the older weaned patients amounting to around 5% per annum, while in the younger age group it is closer to 1.5% per annum (Figures 2–4).

There were nine deaths before discharge: seven who were being still being ventilated died at a mean time of 19.3 weeks, and two who had been weaned died 27.5 weeks after their injury.

Within the weaned group of patients, 17% died within the first 12 months compared with 9% of those on ventilatory

Table 1 Delays in admissions and lengths of stay in the NWRSIC for the two groups

Mode of ventilation on discharge	*Mean*	*s.d.*	*Median*
(a) Admission delay to northwest regional spinal injuries centre in weeks			
Wean	14.3	135.1	0
Ventilation	44.5	115.6	6
Total	23.1	130.1	1
(b) Length of stay at northwest regional spinal injuries centre in weeks			
Wean	35.8	27.0	30
Ventilation	82.8	73.3	69
Total	49.2	49.8	35

Table 2 Distribution of subjects according to neurology and mode of ventilation at time of death or trial end

Motor level	*AIS impairment scale*					
	A		*B*		*C/D*	
	Wean	*Vent*	*Wean*	*Vent*	*Wean*	*Vent*
C1–2	0	32	0	2	9	1
C3–4	31	12	1	4	12	0
C5–8	42	2	16	0	8	0
T1–S5	17	1	2	1	1	0

Abbreviation: AIS, American Spinal Injury Association Impairment Scale.

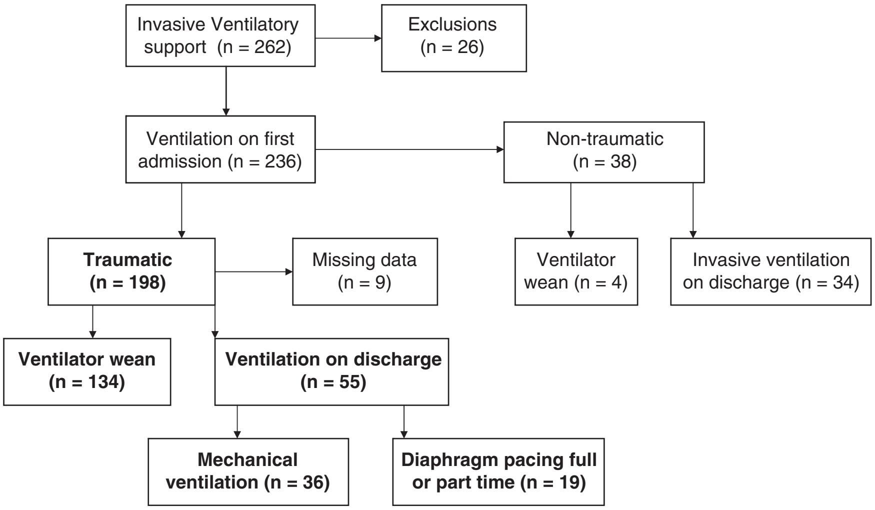

Figure 1 Profile showing numbers having acute ventilatory support after spinal cord injury who were included into study.

support. A comparison then of the 12-month survivors in the two groups showed a 9-month improvement in life expectancy for the ventilated patients in the middle age subgroup, now $7\frac{1}{2}$ years less than the weaned patients and failing to reach statistical significance (Table 4b).

Within the subsets requiring ventilatory support, 19 out of 55 patients used diaphragm pacing either full-time or part-time. When analysed regardless of age, the paced group had a significantly better survival than the group who used only mechanical ventilation; but most of the patients having diaphragm pacing were younger than the mechanical ventilation group.

When analysed according to age, the mean survival time was nearly 2 years better within each age grouping even though the values do not reach levels of statistical significance (Table 5).

In three quarters of cases there was no significant co-morbidity, but the presence of chronic respiratory disease and cardiovascular disease in about 7% appeared to be associated with more deaths in the ventilated group. Because there were small numbers within the individual categories of co-morbidity, they were combined together to assess the importance of any co-morbidity in determining outcome. The weaned patients' mean life expectancy was reduced

Table 3 The initial distribution across five 15-year age bands showing small numbers in outlying cells

Age at injury	*Mode of ventilation on discharge*	*Censored*	*Deceased*
0–15	Wean (2)	0	2
	Ventilation (14)	11	3
16–30	Wean (52)	49	3
	Ventilation (11)	9	2
31–45	Wean (30)	26	4
	Ventilation (16)	9	7
46–60	Wean (37)	22	15
	Ventilation (10)	5	5
61+	Wean (21)	8	13
	Ventilation (4)	2	2

Outer subgroups were then combined to give 79 in the young age group (0–30): 46 in the middle aged group (31–45) and 72 in the age group 46 and over.

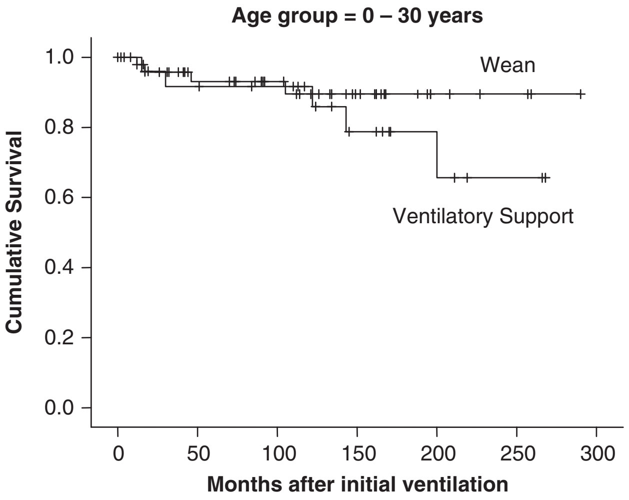

Figure 2 Kaplan–Meier survival curves in months for patients up to 30 years of age, according to ventilatory status on discharge.

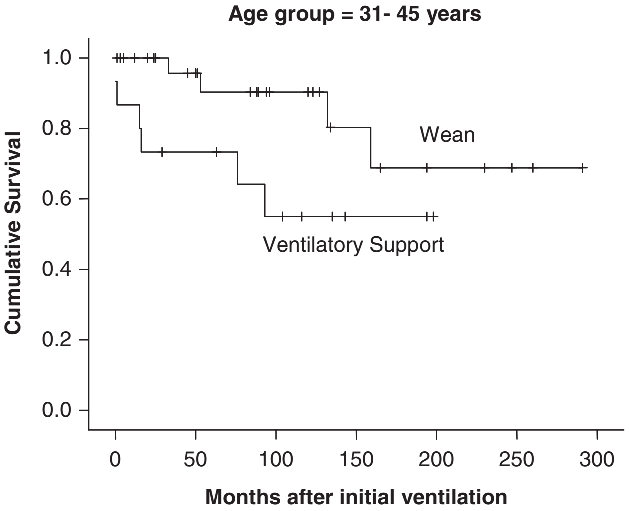

Figure 3 Kaplan–Meier survival curves in months for patients aged 31–45 years of age, according to ventilatory status on discharge.

Table 4 Life expectancy after initial ventilation according to respiratory status at time of death or study end, with a re-analysis for possible adverse weighting due to disproportionate numbers of early deaths

Age group	*Mode of ventilation*				*Log rank P*
	Wean		*Ventilation*		
	Mean	*95% CI*	*Mean*	*95% CI*	
(a) Mean survival in years from time of ventilation (n = 189)					
0–30	22.1	21.2–24	18.4	15.5–21.4	0.312
31–45	19.7	15.8–23.5	10.5	6.8–14.3	0.047
46+	11.0	8.8–13.2	8.1	5–11.3	0.50
(b) Mean survival beyond the first 12 months of initial ventilation (n = 166)					
0–30	21.7	20–23.5	17.5	14.6–20.5	0.191
31–45	18.8	14.9–22.7	11.3	7.8–14.8	0.232
46+	11.3	9.2–13.4	9.3	7.2–12	0.929

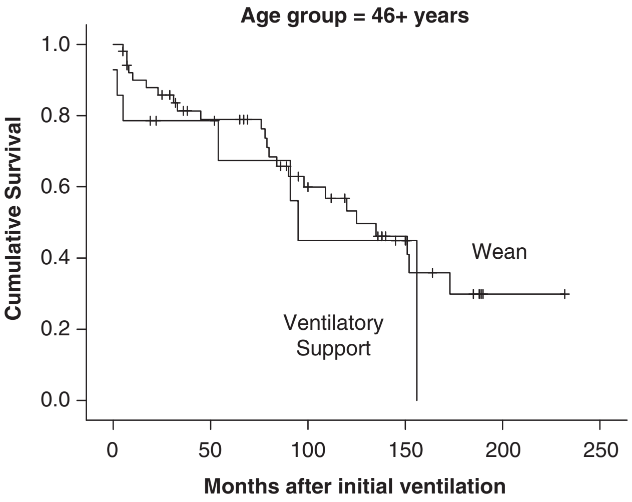

Figure 4 Kaplan–Meier survival curves in months for patients aged over 46 years of age, according to ventilatory status on discharge.

Table 5 Comparison of survival between patients on mechanical ventilation, and those with diaphragm pacing, full-time or part-time

Age group	*Mode of ventilation*				*Log rank*
	Mechanical ventilation		*Diaphragm pacing*		*P*
	Mean	*Numbers*	*Mean*	*Numbers*	
0–30	17.4	(12)	19.2	(13)	0.142
31–45	9.9	(12)	13.1	(3)	0.129
46+	7.9	(12)	10.3	(3)	0.860

Table 6 Cox proportional hazard ratios, significance levels and confidence intervals of categorical variables affecting survival

Variable	*Hazard ratio (Exp B) ± 95% CI*	*Significance level*
Any comorbidity[a]	3.069 (1.383–6.808)	0.006
Mechanical ventilation on discharge[b]	2.260 (1.043–4.897)	0.039
Age 0–30[c]		0.029
Age 31–45	1.353 (0.502–3.469)	0.550
Age 46+	3.102 (1.26–7.847)	0.017
AIS A[d]	1.170 (0.576–2.375)	0.664
Neurological level below T1[e]		0.872
Neurological level C5–C8	1.327 (0.409–4.303)	0.637
Neurological level C0–C4	1.347 (0.432–4.202)	0.608

Abbreviations: AIS, American Spinal Injury Association Impairment Scale.
[a] Reference group: No comorbidity.
[b] Reference group: Patients weaned from mechanical ventilation.
[c] Reference group: Patients 30 years of age or younger.
[d] Reference group: Patients with AIS B, C or D.
[e] Reference group: Patients with neurological level below T1.

Table 7 Causes of death in the two groups

Primary cause of death	*Mode of ventilation*	
	Wean (35)	*Ventilatory support (21)*
Respiratory	20 (57.1%)	12 (57.1%)
Asphyxia	0	2
Cardiovascular	4	2
Cerebrovascular	2	0
Digestive	2	2
Urogenital	0	1
Sepsis	0	1
Cancer	1	0
Unknown	6	0
Percentage of all known respiratory causes	69	66

from 21.4 to 12.0 years by the presence of any co-morbidity, and by the same token the ventilated patients' life expectancy from 17.8 to 5.6 years ($P = 0.004$).

The effect of a variable such as co-morbidity when analysed by Cox regression was to increase the chance of death by around 3 times (Table 6). Dependency upon the ventilator at discharge in this method of analysis significantly increased the chance of death by over two times. Increasing age itself increased the chance of death, but gender, neurological level or AIS scoring had no influence.

Causes of death

Death certificates were available in 46 (82.1%) of the cases, though in three cases with no certificate the cause of death, which was known to the authors, could be coded. From the ONS returns, inquests were known to have been undertaken in 19 cases (41.3%) though in only 3 cases was this accompanied by a post mortem. In the absence of an inquest, 5 cases had had a post mortem and 15 had not.

Respiratory illness was the leading cause of death in 57% in both groups of patients (Table 7). When expressed as a proportion of the known causes of death, respiratory deaths contribute to around two-thirds of all deaths.

Two of the ventilated persons died from accidental disconnection, which was coded as asphyxia (R09.0) though there is no precise ICD coding for this situation. Calculating the incidence of this event as a proportion of the total of 5621 man-ventilator years from this dataset gives a chance of fatal accidental disconnection of 1 in 2810 man-ventilator years. This could equate to a 0.35% life-time risk for a ventilator-dependent person who might be expected to survive 10 years.

Discussion

To the authors' knowledge, this is the largest single-centre study of outcome from mechanical ventilation after acute traumatic spinal cord injury, and for whom the majority of patients had similar care provision and follow-up after discharge, factors that can in themselves strongly influence the outcome.

The follow-up process also ensured authors' knowledge of any change in ventilatory status after discharge. The total number of cases is not sufficient for life-table analysis, and for the same reason age was treated as a categorical variable since there is little difference in the standardized mortality ratios in the patients up to the age of 40, though beyond that there is an 7% increased risk of death for every additional year of life.[5]

The NWRSIC, which covers a population of 6 million, is not a regional trauma centre, so some potential cases may have died on the ventilator before referral, whereas other high-level cases had been referred from outside the core region. Because of the extremely variable length of inpatient stay, the authors used the approach adopted by Wicks and Menter[3] to study survival from the date of injury, and whether or not discharged or still in hospital.

Although the patient data covered 25 years, it has been found that most of the improvement in survival in recent decades took place in the years up to 1979.[13] The retrospective nature of the data collection meant that neurological scoring in the medical records of the earlier cases was not made according to the present AIS system. The motor levels of high-level cases were allocated according to the consensus main segmental level of each of the diaphragm, trapezius and sternomastoids muscles, as the AIS motor scoring system does not enable high-level motor scoring, and the use of the sensory level as a surrogate was not felt to be reliable.

The lack of significance in the Cox analysis of neurological level for outcome can be explained by the small number of segmental levels represented within the ventilator group and because two cases below T1 still on the ventilator died before weaning.

The main findings were that the life expectancy of patients from the NWRISC in England having long-term ventilation after spinal cord injury are in line with the data from model centres in the United States: 18.4 years for those under 30 compared with between 18.6 (age 30) and 21.9 (age 20) for 3-year survivors.[5] Older patients have proportionately lower rates of survival and presence of any co-morbidity halves the survival rates whether remaining ventilated or weaned. The upward revision of life expectancy for those surviving their first year by the latter authors was also found for the ventilator-dependent patients in the middle age group of the present set, but this was not the case for weaned patients in any age group.

The knowledge of two cases of accidental disconnection for the first time allows an estimate of the risk of this occurrence in high-level ventilator-dependent persons to be about 0.03% for every year of ventilation.

It has been of considerable interest whether diaphragmatic pacing offers survival advantages over mechanical ventilation[14] and some indication that this is so is provided by analysing these subgroups separately, although the relatively small numbers do not allow the nearly 2-year difference in survival within each age group to reach statistical significance (Table 6).

In the present study of weaned patients, the 10-year survival within the age group 31–45 was 90% (Figure 3), which is comparable with O'Connor's data for age groups 25–34 (94%), and 35–44 (90.4%) for all non-ventilated, neurological levels.[7] This offers some reassurance that the relatively narrow separation in survival times between ventilated and weaned patients in the present study was not because of a disproportionately poor outcome for weaned patients. Close knowledge of the patients and a slow discharge process had ensured that none of the weaned patients had been inappropriately weaned. The interesting point that emerges is that respiratory causes of mortality feature top of the list for both ventilated patients and the weaned tetraplegic patients, and that it is higher than other reports even though some allowance may be made for the low post-mortem rates and the poor quality of entry of causes of death on death certificates.

There is a considerable risk of fatal respiratory failure with the onset of chest infection in a non-ventilated tetraplegic patient. During the period of this study, 15 not-previously ventilated tetraplegic patients were readmitted to the NWRSIC, of whom seven died and eight were ventilated to be weaned subsequently.

The challenge for clinicians dealing with spinal cord injury is in putting into practice what is already known about helping sputum clearance in non-ventilated tetraplegic patients using various physiotherapy adjuncts,[15,16] early non-invasive respiratory support,[17] and in providing a respiratory training programme that the patient can adhere to over the long term.

For the ventilated tetraplegic patients, successful management of intercurrent chest infections requires cooperation between primary care and the patient's own care team, the tertiary centre and the secondary care sector to which the patient may require admission. This in itself can be problematic unless the patient can be admitted with his usual care providers who help to ensure continuity in care and a positive attitude for recovery.

Conflict of interest

The authors declare no conflict of interest.

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References

1 Goldberg AI. Outcomes of home care for life-supported persons: long term oxygen and prolonged mechanical ventilation. *Chest* 1996; **109**: 595–596.
2 Votto J, Brancifort JM, Scalise PJ, Wollschlager JM, ZeWallack RL. COPD and other diseases in chronically ventilated patients in a prolonged respiratory care unit: a retrospective 20-year survival study. *Chest* 1998; **113**: 86–90.
3 Wicks AB, Menter RR. Long-term outlook in quadriplegic patients with initial ventilator dependency. *Chest* 1986; **90**: 406–410.
4 DeVivo MJ, Ivie CS. Life expectancy of ventilator-dependent persons with spinal cord injuries. *Chest* 1995; **108**: 226–232.
5 Shavelle RM, DeVivo MJ, Strauss DJ, Paculdo DR, Lammertse DP, Day SM. Long-term survival of persons ventilator dependent after spinal cord injury. *J Spinal Cord Med* 2006; **29**: 511–519.
6 DeVivo MJ, Krause J, Lammartse DP. Recent trends in mortality and causes of death among perons with spinal cord injury. *Arch Phys Med Rehabil* 1999; **80**: 1411–1419.
7 O'Connor PJ. Survival after spinal cord injury in Australia. *Arch Phys Med Rehabil* 2005; **86**: 37–47.

8 Frankel HL, Coll JR, Charlifue SW, Whiteneck GG, Garnder BP, Jamous MA *et al*. Long-term survival in spinal cord injury: a fifty year investigation. *Spinal Cord* 1998; **36**: 266–274.

9 Oo TO, Watt JWH, Soni BM, Sett PK. Delayed diaphragm recovery in 12 patients after high spinal cord injury, a retrospective review of the diaphragm status of 107 patients ventilated after acute spinal cord injury. *Spinal Cord* 1999; **37**: 117–122.

10 Atito-Narh E, Pieri-Davies S, Watt JWH. Slow ventilator weaning after cervical spinal cord injury. *Br J Intensive Care* 2008; **18**: 95–102.

11 Maynard FM, Bracken MB, Creasey G, Ditnunno JF, Donovan WH, Ducker TB *et al*. International Standards for neurological and functional classification of spinal cord injury. *Spinal Cord* 1997; **35**: 266–274.

12 Somers MF. Table 7–2. Innervation and action of ventilatory muscles. In: *Spinal Cord Injury. Functional Rehabilitation*, 2nd edn. Prentice-PrenHall International (UK) Ltd, 2001 pp 128–129.

13 Strauss DJ, DeVivo MJ, Paculdo DR, Shavelle RM. Trends in life expectancy after spinal cord injury. *Arch Phys Med Rehabil* 2006; **87**: 1079–1085.

14 Hirschfeld S, Exner G, Luukkaala T, Baer GA. Mechanical ventilation or phrenic nerve stimulation for treatment of spinal cord injury-induced respiratory insufficiency. *Spinal Cord* 2008; **46**: 738–742.

15 Toussaint M, Boitano LJ, Gathot V, Steens M, Soudon P. Limits of effective cough-augmentation techniques in patients with neuromuscular disease. *Respir Care* 2009; **54**: 359–366.

16 Haas CF, Loik PS, Gay SE. Airway clearance applications in the elderly and in patients with neurologic or neuromuscular compromise. *Respir Care* 2007; **52**: 1362–1381.

17 Watt JWH. The role of non-invasive ventilatory support after spinal cord damage. In: Elliott M, Nava S, Schönhofer B. *Principles and Practice of Non-Invasive Ventilation and Weaning*. Hodder Arnold: London, 2010.