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Patterns of use, survival and prognostic factors in patients receiving home mechanical ventilation in Western Australia: A single centre historical cohort study

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Abstract

Home mechanical ventilation (HMV) is used in a wide range of disorders associated with chronic hypoventilation. We describe the patterns of use, survival and predictors of death in Western Australia. We identified 240 consecutive patients (60% male; mean age 58 years and body mass index 31 kg m^{-2}) referred for HMV between 2005 and 2010. The patients were grouped into four categories: motor neurone disorders (MND; 39%), pulmonary disease (PULM; 25%, mainly chronic obstructive pulmonary disease), non-MND neuromuscular and chest wall disorders (NMCW; 21%) and the obesity hypoventilation syndrome (OHS; 15%). On average, the patients had moderate ventilatory impairment (forced vital capacity: 51%predicted), sleep apnoea (apnoea-hypopnea index: 25 events h^{-1}), sleep-related hypoventilation (transcutaneous carbon dioxide rise of 20 mmHg) and daytime hypercarbia (PCO_2: 54 mmHg). Median durations of survival from HMV initiation were 1.0, 4.2, 9.9 and >11.5 years for MND, PULM, NMCW and OHS, respectively. Independent predictors of death varied between primary indications for HMV; the predictors included (a) age in all groups except for MND (hazard ratios (HRs) 1.03–1.10); (b) cardiovascular disease (HR: 2.35, 95% confidence interval (CI): 1.08–5.10) in MND; (c) obesity (HR: 0.28, 95% CI: 0.13–0.62) and oxygen therapy (HR: 0.33, 95% CI: 0.14–0.79) in PULM; and (d) forced expiratory volume in 1 s (%predicted; HR: 0.93, 95% CI: 0.88–1.00) in OHS.

Keywords

Neuromuscular disease, non-invasive ventilation, obesity hypoventilation syndrome, respiratory insufficiency, survival

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Introduction

Chronic hypoventilation complicates a range of disorders including neuromuscular diseases, chronic obstructive pulmonary disease (COPD) and the obesity hypoventilation syndrome (OHS). These disorders lead to chronic hypoventilation when there is an imbalance between respiratory load and muscle capacity, and/or an impairment in respiratory drive.[1,2]

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Chronic hypoventilation has major adverse effects on health care utilization, quality of life and mortality. In recent years, an increasing number of such patients have been treated with home mechanical ventilation (HMV),[3–5] and several studies have reported improvements in gas exchange, hospitalization rates, quality of life and mortality.[3,4,6–8]

There is limited information on survival among patients receiving HMV and factors that influence survival. The Department of Pulmonary Physiology and Sleep Medicine at Sir Charles Gairdner Hospital is one of the major centres providing HMV in Western Australia (WA), and has detailed records of therapy and, because of WA's geographical isolation, low loss to follow-up. In view of these considerations, we aimed to evaluate the patterns of use and factors that may influence survival in patients using HMV. We hypothesized that survival of HMV patients in WA would compare favourably to cohorts in other developed countries, and be predicted by the cause and severity of ventilatory impairment.

Methods

Centre

Our department provides comprehensive diagnostic and therapeutic services for adults with sleep disorders and chronic hypoventilation. It provides both ambulatory services and, for patients with acute ventilatory failure, in-hospital care. Patients are managed by specialist physicians and have access to a pool of ventilators and related equipment and home visits by a specialist nurse. Over the study period, respiratory failure was managed using a consistent approach consisting of full clinical evaluation, in-laboratory polysomnography (PSG), supervised initiation of HMV and regular out-patient clinic follow-up (including monitoring of HMV use and efficacy and measurements of respiratory function and blood gases). Ventilator settings were titrated using a combination of PSG, ventilator download data, blood gases and symptom relief. PSG titrations were performed by experienced sleep scientists. Final pressures were determined after review of the PSG by physicians experienced in the management of ventilatory failure, and settings were adjusted, as needed, at clinic review.

Design, inclusion and exclusion criteria

We conducted a retrospective single-centre cohort study of consecutive patients referred for HMV from January 2005 to December 2010 and followed up to 1 June 2016. Patients were identified from electronic medical records and departmental databases. HMV was defined as non-invasive or invasive (tracheostomy) mechanical ventilation at home or in residential care. All patients who accepted HMV were included. We excluded patients who were prescribed a positive airway pressure device for sleep disordered breathing without hypoventilation or for reasons other than home ventilation (see Figure 1). Ethical approval was obtained from the local institutional research governance body (number 12994).

Data collection

All data were collected by the review of electronic medical records. Variables collected were (a) primary indication for HMV; (b) baseline variables: demographics (age, gender, type of residence and residential address), cardiovascular disease (ischaemic heart disease, heart failure, cardiomyopathy, or atrial fibrillation or flutter), cardiovascular risk factors (hypertension, hyperlipidaemia or diabetes mellitus), smoking status, physiological parameters (spirometry, blood gas and PSG), ventilator prescription (type of interface – non-invasive mask type or tracheostomy, inspiratory positive airway pressure, expiratory positive airway pressure, mode and backup rate); and (c) ventilator adherence (most recent compliance recorded by the ventilator or, if this was unavailable, documented self-reported usage).

Survival outcomes

Survival status was determined at 1 June 2016. Duration of survival was calculated from initiation of HMV to death. Patients were censored on 1 June 2016 if they remained alive or on the date of return of HMV equipment or last date of known HMV use if they ceased HMV or were transferred to another institution for follow-up. Date of death was obtained from hospital electronic medical record maintained by the hospital health information team with direct updates from the WA Department of Health mortality record.

Disease categories

We grouped patients into four clinically meaningful disease categories: motor neurone disease (MND), non-MND neuromuscular and chest wall disorders (NMCW), pulmonary disease (PULM) and OHS. Patients were allocated to the group that best

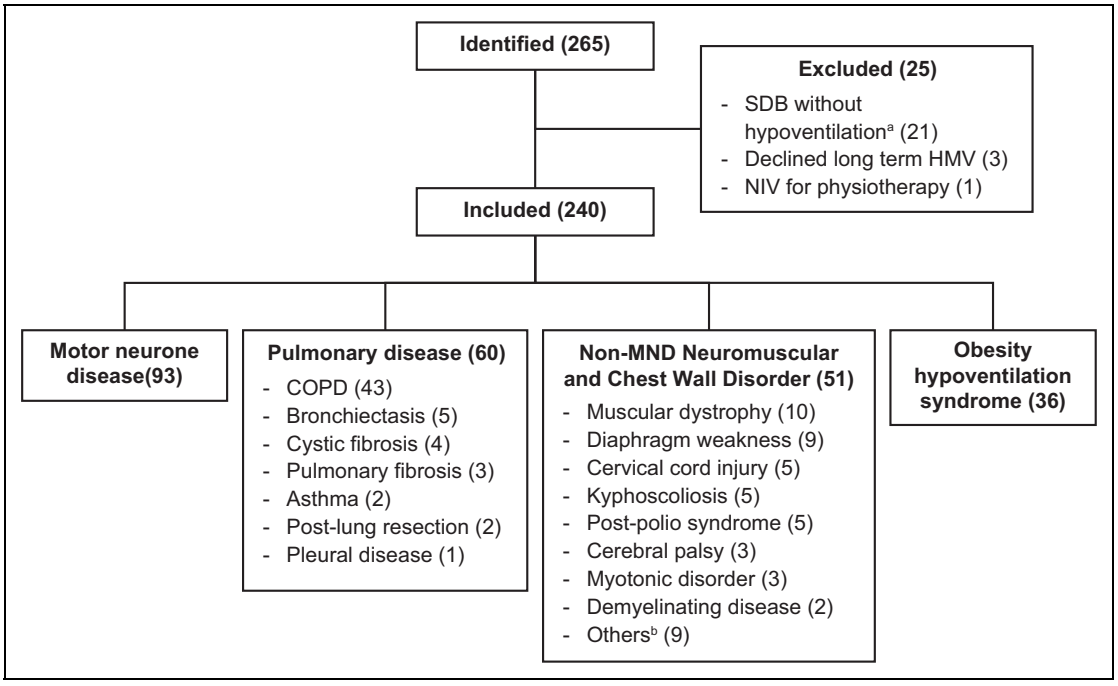

Figure 1. Study flow diagram of patients referred for HMV from January 2005 to December 2010 (6-year period). Number of subjects are displayed in brackets. [a]Sleep disordered breathing without hypoventilation, including mixed obstructive and central sleep apnoea ($n = 12$), treatment-emergent central sleep apnoea ($n = 5$) and obstructive sleep apnoea not controlled by continuous positive airways pressure therapy alone ($n = 4$). [b]Miscellaneous diseases including mitochondrial cytopathy, myasthenia gravis, Bethlem myopathy, spinal muscular atrophy, multisystem atrophy, cystinosis, chronic lower motor neuropathy, myopathy of uncertain aetiology and non-specific respiratory muscle weakness. HMV: home mechanical ventilation; SDB: sleep disordered breathing; NIV: non-invasive ventilation; MND: motor neurone disease.

represented the primary indication for HMV according to physician diagnosis. OHS medical records were closely reviewed to confirm there were no other factors contributing to ventilatory failure. Further details of diseases within the four major groups are shown in Figure 1.

Statistical analysis

Continuous data were described using mean and standard deviation (SD) for parametric data or median and interquartile range (IQR) for non-parametric data. Categorical variables were described using percentage. Survival curves were constructed using Kaplan–Meier survival estimates and plotted as cumulative survival from the initiation of HMV to the end of the study period. Putative predictors of survival were disease group, baseline variables, ventilator settings and adherence (see the 'Data collection' subsection). Predictors of survival measured on a continuous scale were dichotomized where appropriate, using clinically meaningful cut-off values. Log-rank tests were used to compare survival between groups. Univariate predictors with p value < 0.10 were subsequently examined in a forward stepwise multivariable survival analysis using Cox's proportional hazards model. For closely correlated variables, for example, spirometry parameters, the strongest clinical predictor was selected for inclusion in a multivariate model. The proportional hazards assumption was verified to ensure the validity of analyses. Data were presented as hazard ratios (HRs) and associated 95% confidence intervals (CIs) for death. Statistical analyses were conducted using Stata 14.2 (StataCorp, Texas, USA). P values less than 0.05 were considered statistically significant.

Results

A total of 240 patients were included and 149 deaths (62%) were observed over a median (IQR) follow-up of 2.15 (0.69–6.77) years. Fifteen (6.3%) patients ceased HMV therapy, most commonly because of intolerance or lack of symptom benefit and two (0.8%) patients were transferred elsewhere.

Baseline demographics and physiology

Table 1 summarizes the baseline demographic and physiological characteristics of HMV users by disease

Table 1. Baseline demographic and physiological characteristics of HMV groups.[a]

Characteristic	MND ($n = 93$)	PULM ($n = 60$)	NMCW ($n = 51$)	OHS ($n = 36$)
Age (years)	63 (12)	62 (13)	49 (24)	53 (18)
Gender (%male)	75	48	63	39
Current smoker (%user)	10	17	10	33
Body mass index (kg m^{-2})	25.8 (4.8)	30.0 (11.2)	27.7 (9.1)	48.0 (13.2)
Distance[b] (km), median (IQR)	16 (11–29)	14 (9–37)	12 (8–29)	15 (11–35)
Any CV disease[c] (%user)	12	37	24	44
Any CV risk factors[c] (%user)	39	45	41	67
Spirometry				
Available data (%user)	83	93	86	89
FEV_1 (L)	1.97 (0.87)	0.81 (0.35)	1.01 (0.48)	1.71 (0.99)
FEV_1 (%predicted)	63 (23)	29 (11)	36 (17)	56 (21)
FVC (L)	2.45 (1.14)	1.74 (0.80)	1.22 (0.63)	2.15 (1.25)
FVC (%predicted)	59 (23)	49 (17)	35 (17)	56 (21)
FEV_1/FVC ratio (%)	82 (12)	50 (18)	84 (12)	80 (10)
Blood gas				
Available data (%user)	45	98	78	84
PCO_2 (mmHg)	46 (10)	58 (10)	53 (11)	56 (11)
Bicarbonate (mmol L^{-1})	29 (5)	34 (5)	31 (4)	32 (5)
PSG				
Available data (%user)	42	90	69	97
AHI (events h^{-1}), median (IQR)	17 (11–46)	24 (12–43)	29 (14–68)	72 (22–126)
Nadir SpO_2 (%)	84 (7)	76 (11)	77 (12)	69 (15)
SpO_2 < 90% (%TRT), median (IQR)	0 (0–3)	22 (4–41)	12 (2–30)	38 (9–61)
$TcCO_2$ high[d] (mmHg)	62 (15)	74 (13)	69 (17)	72 (14)
$\Delta TcCO_2$[d] (mmHg)	19 (12)	20 (12)	19 (12)	22 (13)

HMV: home mechanical ventilation; MND: motor neurone disease; PULM: pulmonary disease; NMCW: non-MND neuromuscular and chest wall disorder; OHS: obesity hypoventilation syndrome; IQR: interquartile range; CV: cardiovascular; FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; PSG: polysomnography; SpO_2: oxygen saturation measured by pulse oximetry; TRT: total recording time; $TcCO_2$: transcutaneous carbon dioxide; $\Delta TcCO_2$: the difference between the highest sleep and lowest awake $TcCO_2$; SD: standard deviation; AHI: apnoea-hypopnea index.

[a]Data are expressed as mean (SD) unless otherwise stated.

[b]Geodesic distance from residence postcode to our centre.

[c]Cardiovascular disease includes ischaemic heart disease, history of heart failure, cardiomyopathy or atrial fibrillation/flutter. Risk factors include hypertension, hyperlipidaemia or diabetes mellitus.

[d]$TcCO_2$ was measured in >70% of PSG.

category. Data were available in >80% of patients for all variables except for blood gas and PSG parameters in MND (45% and 42%, respectively) and NMCW (78% and 69%, respectively) patients.

All groups had moderate ventilatory impairment. Sleep disordered breathing was prevalent; median apnoea–hypopnea index (AHI) was ≥ 15 h^{-1} and sleep-related hypoventilation,[9] based on transcutaneous carbon dioxide (CO_2) monitoring, was present.

HMV prescription and usage characteristics

HMV prescription indications and characteristics are shown in Table 2. All patients received bi-level pressure-cycled positive pressure ventilation. Two patients (one each in PULM and NMCW groups) were ventilated via tracheostomy; the remainder received therapy non-invasively. The frequency of PSG titration varied by disease group (OHS 92%, NMCW 80%, PULM 78% and MND 16%). Average (SD) adherence to therapy was 7.9 (4.3) h day^{-1}.

Survival estimates

Median duration of survival (95% CI) for the groups were 1.0 (0.7 to 1.3), 4.2 (2.5 to 9.5), 9.9 (5.7 to >11.5) and >11.5 (8.2 to >11.5) years for MND, PULM, NMCW and OHS, respectively (Figure 2). Corresponding 1-year survival probabilities were 52%, 78%, 96% and 97%; 5-year survival probabilities

Table 2. HMV prescription and usage characteristics of HMV groups.[a]

Characteristic	MND ($n = 93$)	PULM ($n = 60$)	NMCW ($n = 51$)	OHS ($n = 36$)
Reasons for initiation (%users)				
In-patient	11	70	65	44
Chronic hypercarbic respiratory failure	19	23	18	31
Sleep hypoventilation only	24	7	12	25
Symptoms only[b]	45	0	6	0
Non-invasive interface (%users)	100	98	98	100
Spontaneous-timed trigger (%users)	84	78	86	67
Inspiratory positive airway pressure (cmH_2O)	14 (2)	18 (3)	17 (3)	20 (3)
Expiratory positive airway pressure (cmH_2O)	6 (2)	9 (3)	9 (3)	12 (3)
Backup rate (min^{-1})	12 (2)	13 (2)	13 (2)	12 (2)
Oxygen therapy (%users)	4	73	18	33
Usage above 4 h day^{-1} (%users)[c]	70	88	84	78

HMV: home mechanical ventilation; MND: motor neurone disease; PULM: pulmonary disease; NMCW: non-MND neuromuscular and chest wall disorder; OHS: obesity hypoventilation syndrome; SD: standard deviation.
[a]Data are presented as mean (SD) unless otherwise stated.
[b]Symptoms included dyspnoea, orthopnoea, witnessed apnoea, snoring, choking sensation, sleep disruption, poor sleep quality, headache, fatigue or daytime somnolence.
[c]Compliance data are based on latest available self-reported or device download data. It is available in 68%, 80%, 84% and 89% of the four corresponding groups.

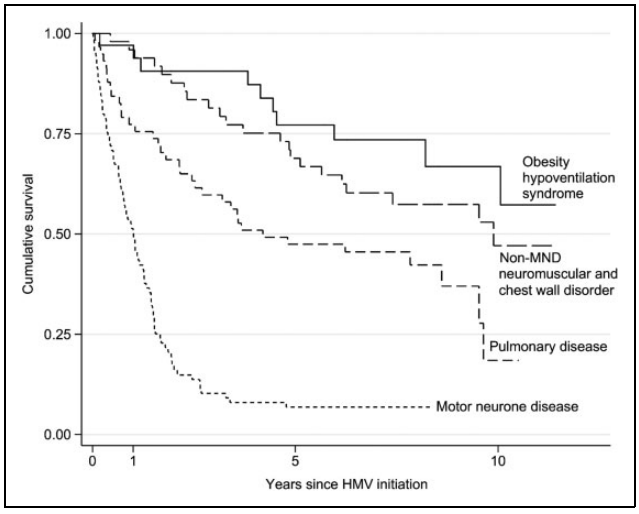

Figure 2. Kaplan–Meier estimates of cumulative survival by disease categories. Between-group survival estimates are different ($p < 0.01$) except for NMCW and OHS groups ($p = 0.43$). Median survival durations are 1.0, 4.2, 9.9 and >11.5 years for MND, PULM, NMCW and OHS groups, respectively. Corresponding 1-year survival probabilities are 52%, 78%, 96% and 97%; 5-year survival probabilities are 7%, 48%, 69% and 77%. MND: motor neurone disease; OHS: obesity hypoventilation syndrome; MND: motor neurone disease; PULM: pulmonary disease; NMCW: non-MND neuromuscular chest wall disorders.

were 7%, 48%, 69% and 77%. The survival estimates were different between disease categories ($p < 0.001$) except between NMCW and OHS ($p = 0.31$).

Factors influencing survival

Univariate analysis. Important predictors of death (HR, 95% CI) for MND were age (1.02, 1.00–1.04), cardiovascular disease (1.98, 1.02–3.83) and risk factors (1.64, 1.05–2.58), and baseline lung function (forced expiratory volume in 1 s (FEV_1; 0.71, 0.52–0.98) and forced vital capacity (FVC; 0.79, 0.63–0.99)). In PULM, age (1.04, 1.01–1.08), FEV_1 (0.32, 0.11–0.96) and oxygen therapy (0.46, 0.22–0.94) were significant prognostic factors. In NMCW group, older age (1.03, 1.01–1.05) and use of oxygen therapy (3.30, 1.25–8.66) were associated with poorer survival. In OHS, older age (1.06, 1.01–1.11), cardiovascular disease (11.23, 2.23–56.47) and worse daytime hypercarbia (5.00, 1.16–21.51) at baseline were predictors of death. Table 3 shows the univariate HR and 95% CI of important predictors by disease groups.

Multivariate analysis. Independent predictors of death included (a) age in all groups except for MND with HR ranging from 1.03 to 1.10; (b) cardiovascular disease (2.35, 1.08–5.10) in MND; (c) obesity (0.28, 0.13–0.62) and oxygen therapy (0.33, 0.14–0.79) in PULM; and (d) FEV_1 (%predicted; 0.93, 0.88–1.00) in OHS (see Table 4).

Discussion

This is the first historical cohort study of HMV in WA, and one of relatively few studies of patterns of

Table 3. Univariate Cox proportional hazards regression analysis of predictors of death among patients treated with HMV.[a]

Predictors	MND	PULM	NMCW	OHS
Age[b] (years)	1.02 (1.00–1.04)[b]	1.04 (1.01–1.08)[c]	1.03 (1.01–1.05)[c]	1.06 (1.01–1.11)[c]
Male	–	–	0.49 (0.21–1.13)[d]	–
Obesity	0.56 (0.31–1.00)[d]	0.30 (0.14–0.66)[c]	–	–
Any CV disease	1.98 (1.02–3.83)[c]	–	–	11.23 (2.23–56.47)[c]
Any CV risk factors	1.64 (1.05–2.58)[c]	–	–	–
FEV_1[b] (L)	0.71 (0.52–0.98)[c]	0.32 (0.11–0.96)[c]	–	–
%predicted FEV_1[b]	0.99 (0.97–1.00)[c]	–	–	0.96 (0.91–1.00)[d]
FVC[b] (L)	0.79 (0.63–0.99)[c]	–	–	–
%predicted FVC[b]	0.99 (0.98–1.00)[c]	–	–	0.94 (0.89–1.00)[d]
$PCO_2 \geq 60$ mmHg	–	–	–	5.00 (1.16–21.51)[c]
Bicarbonate ≥ 35 mmol L^{-1}	–	–	–	5.58 (1.31–23.79)[d]
ST trigger	1.65 (0.91–3.00)[d]	–	–	–
Backup rate[b]	1.13 (0.98–1.30)[d]	–	–	–
Oxygen therapy	–	0.46 (0.22–0.94)[c]	3.30 (1.25–8.66)[c]	–

HMV: home mechanical ventilation; MND: motor neurone disease; PULM: pulmonary disease; NMCW: non-MND neuromuscular and chest wall disorder; OHS: obesity hypoventilation syndrome; CV: cardiovascular; FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; ST: spontaneous-timed; HR: hazard ratio; CI: confidence interval.
[a]Data are presented as HR (95% CI). Only variables with $p \leq 0.10$ in at least one disease category are displayed in the table.
[b]Continuous variables; HR describes per unit increment.
[c]$p < 0.05$.
[d]$0.05 \leq p < 0.1$.

Table 4. Multivariate Cox proportional hazards regression analysis of independent predictors of death among patients treated with HMV.[a]

	MND	PULM	NMCW	OHS
Available data, *n* (%)	60 (65)	55 (92)	51 (100)	27 (75)
Age[b] (years)	–	1.07 (1.03–1.11)	1.03 (1.01–1.05)	1.10 (1.00–1.20)
Obesity	–	0.28 (0.13–0.62)	–	–
Any CV disease	2.35 (1.08–5.10)	–	–	–
%predicted FEV_1[b]	–	–	–	0.93 (0.88–1.00)
Oxygen therapy	–	0.33 (0.14–0.79)	–	–

HMV: home mechanical ventilation; MND: motor neurone disease; PULM: pulmonary disease; NMCW: non-MND neuromuscular and chest wall disorder; OHS: obesity hypoventilation syndrome; CV: cardiovascular; FEV_1: forced expiratory volume in 1 s; HR: hazard ratio; CI: confidence interval.
[a]Data are presented as HR (95% CI). Variables with $p < 0.05$ are displayed.
[b]Continuous variables; HR describes per unit increment.

use, long-term survival and prognostic factors in patients on HMV anywhere in the world.[10–14] We found that the main indications for HMV use were MND, PULM (mainly COPD) and OHS, similar to that reported in other surveys conducted in Australia and Europe. Our patients were predominant middle-aged, received HMV non-invasively, and there was a high prevalence of obesity, co-morbid sleep apnoea and sleep-related hypoventilation. Survival was strongly related to the primary indication for HMV, with the shortest survival for MND and progressively increasing survival durations for PULM, NMCW and OHS. Median survival durations for these disease groups were similar to previous European cohorts.[4,10,11] We confirmed several independent prognostic factors found in previous studies; in particular, younger patients had better survival in PULM and NMCW, obesity was protective in PULM and higher baseline respiratory function reduced the hazard of death in OHS. We also reported new findings of shorter survival for MND in the presence of concomitant cardiovascular disease and for older OHS patients.

The patterns of HMV use vary considerably between countries and between regions within

countries depending on local facilities, funding, advocacy and variations in practice. Compared to a cross-sectional study in Australia and New Zealand[14] and a 10-year cohort study in Sweden,[10] our cohort had a higher proportion of patients with MND (38.8%) and PULM (25%) and a lower proportion with NMCW (21.3%) and OHS (15%). The shorter survival of MND and PULM patients could account, at least in part, for their higher proportion in our cohort study compared to a cross-sectional study. The numbers of patients receiving invasive mechanical ventilation were lower than many centres in Europe and North America[13–16] but similar to usual practice in Australia and New Zealand.[14] Daily use of HMV was high, and consistent with levels of compliance found in previous studies.[11,17]

Factors influencing survival

MND group. Consistent with previous studies,[4,18,19] obesity and better respiratory function were associated with higher survival in MND in univariate analysis. Indeed, elevated BMI has been independently associated with improved survival in patients using HMV with a range of causes for chronic ventilatory failure.[11] The association of increasing age with shorter MND survival may be due to reduced motor neuron 'reserve' in older patients. Spontaneous-time trigger mode and higher backup rate were associated with worse survival in MND. To our knowledge, these associations have not been previously reported and may be markers of greater ventilatory impairment at initiation of HMV. Co-existing cardiovascular disease and risk factors were univariately associated with poorer survival, and cardiovascular disease was the only independent risk factor for MND survival. To our knowledge, this association has not been previously reported. Although the most common cause of death in MND is respiratory failure,[20] sudden death (likely cardiac aetiology) has also been described.[18]

PULM group. The PULM group included 43 COPD subjects (72%); the COPD subjects were marginally older (mean 65 vs. 62 years) and had a slightly higher proportion of males (55 vs. 50%), but physiological findings, survival estimates and predictors of survival were similar to the entire PULM group. The survival outcomes of COPD and PULM patients compare favourably with those reported in several randomized controlled trials of HMV in COPD.[21–23] The levels of pressure support used in our study are similar to those used in these early studies.[21–23] More recent studies using higher levels of pressure support have shown higher 1-year survival.[24]

In PULM disease, we confirm previously described associations between improved survival and younger age[10,11] and obesity.[25,26] In COPD, cachexia is associated with systemic inflammation, adverse metabolic changes and reduced survival.[27–29] An unexpected new association of oxygen therapy and improved survival in the PULM group in our study probably reflects a Western Australian policy of prohibiting oxygen therapy prescription to current smokers. We found a strong negative relationship between oxygen therapy and smoking status ($p = 0.002$, Fisher's exact; results not shown). Thus, the positive association of oxygen therapy with improved survival in our cohort may be due to a combination of improved oxygenation[30] and smoking cessation.

NMCW group. Consistent with findings in Sweden, there was a univariate association between oxygen therapy and increased mortality in NMCW; this has been attributed to either suboptimal ventilatory therapy or concomitant pulmonary parenchymal disease.[10] In our cohort, only increasing age was independently associated with increased mortality, presumably because it is a marker of both more advanced disease and reduced overall health status and reserve. Male patients had a trend towards better prognosis on univariate analysis and this is likely due to high proportion of male muscular dystrophy patients who had better survival (median 9.7 (6.2–11.8) years).

OHS group. Percentage predicted FVC and FEV_1 were both univariately associated with mortality in OHS, and the latter was the strongest and an independent predictor. These findings are consistent with those of Ojeda Castillejo et al.,[31] who attributed this relationship to more advanced structural changes at the time of diagnosis. We also found baseline CO_2 and bicarbonate were univariate predictors of mortality, possibly a reflection of relatively late presentation to medical attention. Borel et al. found that HMV patients with obesity and hypercapnia taking a combination of cardiovascular drugs were at increased risk of death.[17] Our findings are consistent with those of Borel, except our univariate association of mortality and a history of cardiovascular disease lost significance in the multivariate model, possibly because of the relatively small OHS sample size. Increased age was associated with

lower survival. To our knowledge, this association has not been previously reported. The mean age of our OHS patients was lower than in previous cohorts[17,31,32] and this raises the possibility of a survival advantage with diagnosis and initiation of HMV early in the natural history of the disease.

Limitations

Data were incomplete on some patients, likely due to variations in practices between physicians, the important role of clinically based treatment decisions in rapidly progressive (e.g. MND[33]) or very advanced disease and, in some cases, patient preferences. The study did not consider the effect of nutritional advice or supplementary enteral feeding on survival.

We describe HMV treatment from a single centre; however, the number of HMV patients managed in secondary public centres or privately in WA is relatively small. Based on a statewide database of applications for HMV funding support, we estimate that our centre managed 75–80% of all patients who received HMV in WA during the study period.

Conclusions

The patterns of HMV use and survival for sleep hypoventilation and daytime ventilatory failure in WA are similar to those of cohorts in other developed countries, except for our infrequent use of invasive ventilation. Clinical disease group was an important predictor of survival. We confirm the importance of several previously identified independent predictors of reduced survival including, depending on the disease group, older age, lower FEV_1 and absence of obesity. We report, for the first time, reduced survival in MND with co-existing cardiovascular disease and in older OHS patients. Our findings provide useful data to enhance decision-making by physicians, patients and their carers and for future healthcare planning and resource allocation.

Authors' note

The work was conducted at the West Australian Sleep Disorders Research Institute Internal Mailbox 201, Queen Elizabeth II Medical Centre, Hospital Avenue. Perth, Western Australia 6009, Australia.

Authors' contribution

Geak Tan, Nigel McArdle and Bhajan Singh contributed to the study conception and design. Geak Tan, Jane Douglas and Clare Siobhan Rea collected the data. Geak Tan, Nigel McArdle and Bhajan Singh analysed and interpreted the data with assistance from Satvinder Dhaliwal. Geak Tan, Nigel McArdle, Satvinder Dhaliwal and Bhajan Singh drafted the manuscript. All authors revised the manuscript and approved the final version for submission. Geak Tan, Nigel McArdle and Bhajan Singh are responsible for the integrity of the study and have full access to the data. Bhajan Singh is the guarantor of the study. Please contact the authors if the primary data of this study are required.

Declaration of conflicting interests

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References

1. Roussos C and Koutsoukou A. Respiratory failure. *Eur Respir J Suppl* 2003; 47: 3s–14s.
2. Hillman D, Singh B, McArdle N, et al. Relationships between ventilatory impairment, sleep hypoventilation and type 2 respiratory failure. *Respirology* 2014; 19: 1106–1116.
3. Radunovic A, Annane D, Rafiq MK, et al. Mechanical ventilation for amyotrophic lateral sclerosis/motor neuron disease. *Cochrane Database Syst Rev* 2013; 2013: Cd004427.
4.. Chiò A, Calvo A, Moglia C, et al. Non-invasive ventilation in amyotrophic lateral sclerosis: a 10 year population based study. *J Neurol Neurosurg Psychiatry* 2012; 83: 377–381.
5. Simonds AK. Home mechanical ventilation: an overview. *Ann Am Thorac Soc* 2016; 13: 2035–2044.
6. MacIntyre EJ, Asadi L, McKim DA, et al. Clinical outcomes associated with home mechanical ventilation: a systematic review. *Can Respir J* 2016; 2016: 6547180.
7. Annane D, Orlikowski D, and Chevret S. Nocturnal mechanical ventilation for chronic hypoventilation in patients with neuromuscular and chest wall disorders. *Cochrane Database Syst Rev* 2014; 2014: Cd001941.

8. Calvert LD, McKeever TM, Kinnear WJ, et al. Trends in survival from muscular dystrophy in England and Wales and impact on respiratory services. *Respir Med* 2006; 100: 1058–1063.
9. Berry RB, Brooks R, Gamaldo CE, et al. *The AASM manual for the scoring of sleep and associated events: rules, terminology and technical specifications, version 2.4*. Darien, IL: American Academy of Sleep Medicine, 2017.
10. Laub M and Midgren B. Survival of patients on home mechanical ventilation: a nationwide prospective study. *Respir Med* 2007; 101: 1074–1078.
11. Budweiser S, Jörres RA, Criee CP, et al. Prognostic value of mouth occlusion pressure in patients with chronic ventilatory failure. *Respir Med* 2007; 101: 2343–2351.
12. Chailleux E, Fauroux B, Binet F, et al. Predictors of survival in patients receiving domiciliary oxygen therapy or mechanical ventilation. A 10-year analysis of ANTADIR Observatory. *Chest* 1996; 109: 741–749.
13. Lloyd-Owen SJ, Donaldson GC, Ambrosino N, et al. Patterns of home mechanical ventilation use in Europe: results from the Eurovent survey. *Eur Respir J* 2005; 25: 1025–1031.
14. Garner DJ, Berlowitz DJ, Douglas J, et al. Home mechanical ventilation in Australia and New Zealand. *Eur Respir J* 2013; 41: 39–45.
15. Divo MJ, Murray S, Cortopassi F, et al. Prolonged mechanical ventilation in Massachusetts: the 2006 prevalence survey. *Respir Care* 2010; 55: 1693–1698.
16. King AC. Long-term home mechanical ventilation in the United States. *Respir Care* 2012; 57: 921–930.
17. Borel JC, Burel B, Tamisier R, et al. Comorbidities and mortality in hypercapnic obese under domiciliary non-invasive ventilation. *PLoS One* 2013; 8: e52006.
18. Dreyer P, Lorenzen CK, Schou L, et al. Survival in ALS with home mechanical ventilation non-invasively and invasively: a 15-year cohort study in West Denmark. *Amyotroph Lateral Scler Frontotemporal Degener* 2014; 15: 62–67.
19. Calvo A, Moglia C, Lunetta C, et al. Factors predicting survival in ALS: a multicenter Italian study. *J Neurol* 2017; 264: 54–63.
20. Kiernan MC, Vucic S, Cheah BC, et al. Amyotrophic lateral sclerosis. *Lancet* 2011; 377: 942–955.
21. McEvoy RD, Pierce RJ, Hillman D, et al. Nocturnal non-invasive nasal ventilation in stable hypercapnic COPD: a randomised controlled trial. *Thorax* 2009; 64: 561–566.
22. Clini E, Sturani C, Rossi A, et al. The Italian multicentre study on noninvasive ventilation in chronic obstructive pulmonary disease patients. *Eur Respir J* 2002; 20: 529–538.
23. Casanova C, Celli BR, Tost L, et al. Long-term controlled trial of nocturnal nasal positive pressure ventilation in patients with severe COPD. *Chest* 2000; 118: 1582–1590.
24. Kohnlein T, Windisch W, Köhler D, et al. Non-invasive positive pressure ventilation for the treatment of severe stable chronic obstructive pulmonary disease: a prospective, multicentre, randomised, controlled clinical trial. *Lancet Respir Med* 2014; 2: 698–705.
25. Altinoz H, Adiguzel N, Salturk C, et al. Obesity might be a good prognosis factor for COPD patients using domiciliary noninvasive mechanical ventilation. *Int J Chron Obstruct Pulmon Dis* 2016; 11: 1895–1901.
26. Cao C, Wang R, Wang J, et al. Body mass index and mortality in chronic obstructive pulmonary disease: a meta-analysis. *PLoS One* 2012; 7: e43892.
27. Broekhuizen R, Grimble RF, Howell WM, et al. Pulmonary cachexia, systemic inflammatory profile, and the interleukin 1beta-511 single nucleotide polymorphism. *Am J Clin Nutr* 2005; 82: 1059–1064.
28. Schols AM. Pulmonary cachexia. *Int J Cardiol* 2002; 85: 101–110.
29. Schols AM, Slangen J, Volovics L, et al. Weight loss is a reversible factor in the prognosis of chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1998; 157: 1791–1797.
30. Cranston JM, Crockett AJ, Moss JR, et al. Domiciliary oxygen for chronic obstructive pulmonary disease. *Cochrane Database Syst Rev* 2005; 2005: Cd001744.
31. Ojeda Castillejo E, de Lucas Ramos P, López Martin S, et al. Noninvasive mechanical ventilation in patients with obesity hypoventilation syndrome. Long-term outcome and prognostic factors. *Arch Bronconeumol* 2015; 51: 61–68.
32. Priou P, Hamel JF, Person C, et al. Long-term outcome of noninvasive positive pressure ventilation for obesity hypoventilation syndrome. *Chest* 2010; 138: 84–90.
33. Eng D. Management guidelines for motor neurone disease patients on non-invasive ventilation at home. *Palliat Med* 2006; 20: 69–79.