Pressure support ventilation in intensive care patients receiving prolonged invasive ventilation

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Invasive mechanical ventilation can be delivered via a mandatory or spontaneous ventilation mode.[1] Choice of mode depends on patient factors, familiarity and clinician preference. Choice may also vary according to country and centre because there is no high quality evidence to guide practice.[1] During mandatory ventilation, a tidal volume (Vt) of 6–8 mL/kg of predicted bodyweight (PBW), a plateau pressure of less than 30 cmH_20, and a driving pressure of less than 15 cmH_2O are recommended, especially in patients with acute respiratory distress syndrome.[2,3] However, for pressure support ventilation (PSV), there is no strong evidence to guide the level of pressure support (PS) and target Vt.

The proposed advantages of PSV over mandatory ventilation include its potential to improve respiratory muscle strength,[4,5] reduce sedation requirements,[3,6] and assist clinicians in determining the readiness of patients to be liberated from the ventilator.[7] However, in contrast to mandatory ventilation, there is no evidence on the use and management of PSV in patients receiving prolonged ventilation. There is also little information to guide clinicians in terms of optimal PSV practice.[8-10] Some authors suggest targeting a low Vt,[11,12] but others recommend assessment of accessory muscle activity to determine the adequacy of a given PS level.[13] In patients receiving prolonged ventilation, there are no data on key aspects of management. These include the timing of PSV initiation; the duration of PSV use; the level of PS applied; the delivered Vt size and respiratory rate; the changes in respiratory variables after transition from mandatory ventilation to PSV; and the percentage of time spent on PSV. Yet this information is essential for designing interventional studies that aim to improve the management of PSV.

ABSTRACT

Background: To our knowledge, the use and management of pressure support ventilation (PSV) in patients receiving prolonged (≥ 7 days) invasive mechanical ventilation has not previously been described.

Objective: To collect and analyse data on the use and management of PSV in critically ill patients receiving prolonged ventilation.

Design, setting and participants: We performed a multicentre retrospective observational study in Australia, with a focus on PSV in patients ventilated for ≥ 7 days.

Main outcome measures: We obtained detailed data on ventilator management twice daily (8am and 8pm moments) for the first 7 days of ventilation.

Results: Among 143 consecutive patients, 90/142 (63.4%) had received PSV by Day 7, and PSV accounted for 40.5% (784/1935) of ventilation moments. The most common pressure support level was 10 cmH_2O (352/780) observations [45.1%]) with little variation over time, and 37 of 114 patients (32.4%) had no change in pressure support. Mean tidal volume during PSV was 8.3 (7.0–9.5) mL/kg predicted bodyweight (PBW) compared with 7.5 (7.0–8.3) mL/kg PBW during mandatory ventilation ($P < 0.001$). For 74.6% (247/331) of moments, despite a tidal volume of more than 8 mL/kg PBW, the pressure support level was not changed. Among 122 patients exposed to PSV, 97 (79.5%) received likely over-assistance according to rapid shallow breathing index criteria. Of 784 PSV moments, 411 (52.4%) were also likely over-assisted according to rapid shallow breathing index criteria, and 269/346 (77.7%) having no subsequent adjustment of pressure support.

Conclusions: In patients receiving prolonged ventilation, almost two-thirds received PSV, which accounted for 40.5% of mechanical ventilation time. Half of the PSV-treated patients were exposed to high tidal volume and two-thirds to likely over-assistance. These observations provide evidence that can be used to inform interventional studies of PSV management.

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Accordingly, we conducted a retrospective observational multicentre study of patients receiving invasive mechanical ventilation for more than 1 week. We aimed to test three hypotheses regarding patients receiving prolonged ventilation: the primary hypothesis that more than a third of total ventilation time would be spent on PSV; and the secondary hypotheses that Vt would be significantly greater during PSV than during mandatory ventilation, and that likely over-assistance would be common.

Methods

Study design

This was a multicentre retrospective observational study of invasive ventilation practice in five mixed medical–surgical adult intensive care units (ICUs) in Victoria, Australia, with a focus on PSV. Three ICUs were in tertiary hospitals and two were in regional hospitals. The study was approved by the ethics committees of all the participating institutions with a waiver of informed consent (ethics approval number, LNR/17/Austin/265).

Participants

We included ≥ 20 consecutive adult patients (aged ≥ 18 years) admitted to each participating ICU who received invasive ventilation from March 2017 to August 2019. The main inclusion criterion was prolonged ventilation, defined as receiving ventilation for 7 or more days. We excluded patients receiving extracorporeal membrane oxygenation, patients receiving palliative care, and heart and lung transplant patients. We only considered first (index) ICU admission data.

Data collection

We collected data for 7 consecutive days, starting on the first day of ventilation, and at two "moments" per day (8am and 8pm). Thus, all patients had 14 measurements of ventilatory variables, sedative doses (midazolam, morphine, fentanyl and propofol), and arterial blood gas levels. In addition, we collected baseline data and admission diagnoses. We collected all data from electronic health records.

Definitions

For every patient, the number of hours on PSV, on synchronised intermittent mandatory ventilation (SIMV), on T-piece ventilation, on other modes of ventilation (eg, assist control ventilation), or without invasive ventilation (for those re-intubated during the 7-day study period) were calculated, with the maximum being 168 hours (7 days). In addition, we calculated the percentage of time spent on PSV, defined as the number of hours on PSV divided by 168.

We calculated PBW in kg using a standard formula: 50 + 0.91 × (height [cm] – 152.4) for males; and 45.5 + 0.91 × (height [cm] – 152.4) for females. We calculated the rapid shallow breathing index (RSBI) in breaths/min/L as: respiratory rate (breaths/min) ÷ tidal volume (L). We calculated the cumulative doses of sedatives as the sum of all doses available in the 14 moments of measurement per patient. Moments without the use of the sedative of interest were coded as 0. We calculated the mean daily doses of sedatives, and the mean values for arterial blood gas levels, as means of all measurements available for these variables. Finally, we recorded the lowest and highest values for all measurements.

To understand the prevalence of over-assistance during PSV, we used two definitions of "likely over-assistance" as previously reported: respiratory rate ≤ 17 breaths/min and/or RSBI ≤ 37 breaths/min/L.[12,14] In addition, we calculated the variation in PS levels during the period of observation as the coefficient of variation per patient, defined as the standard deviation of the PS level divided by its mean (presented as percentage).

Outcomes

The primary outcome of the study was the percentage of invasive ventilation time spent on PSV compared with other modes in the first 7 days of ventilation. Secondary outcomes were Vt size delivered during mechanical ventilation (before and during PSV compared with mandatory ventilation) and the prevalence of likely over-assistance during PSV. In addition, we report data on ICU length of stay, hospital length of stay, ICU mortality and hospital mortality.

Statistical analyses

We report continuous variables as median and interquartile range (IQR; quartile 25% to quartile 75%) and categorical variables as number and percentage. Each measurement was classified according to mode of ventilation at the time it was taken (PSV, SIMV or other). We compared the cumulative doses of sedatives, the mean, lowest and highest values for ventilatory variables, and arterial blood gas levels, according to use of PSV at time of measurement (PSV versus no PSV) using median differences and 95% confidence intervals. We calculated median differences using a mixed-effect quantile model considering a $\tau = 0.50$ and an asymmetric Laplace distribution. We obtained *P* values after 1000 bootstrap samples. Due to within-patient data clustering, we included patients as a random effect. We compared continuous variables between three or more groups using the Kruskal–Wallis test.

We further divided patients according to first ventilation mode, and according to the most used mode (the most frequently reported mode in the 14 assessments

available). To expand the findings, we assessed the changes in ventilatory variables due to transition to PSV. We compared moments classified as immediately before transition (moment exactly before the first transition to PSV), immediately after transition (moment exactly after the first transition to PSV), and 24 hours after transition (moment 24 hours after the first transition to PSV and considered only when PSV was still the mode being used).

We present ventilatory variables in cumulative distribution plots considering an empirical cumulative distribution function. This type of plot represents the cumulative distribution of the variable of interest according to all measurements assessed. We performed all analyses using R version 4.0.2 (R Core Team).

Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Results

Patients

We studied 143 consecutive patients. Of them, 94 (65.7%) were men, the median age was 62.0 years, and the median APACHE III score was 68.0 (IQR, 39.5–89.5). Most were medical patients admitted due to a respiratory condition (Table 1). ICU and hospital mortality rates were 27.9% and 44.3%, respectively.

Mechanical ventilation practice

The ventilation mode was available for 1935 available moments (96.7%), with 784 (40.5%) classified as PSV, 884 (45.7%) as SIMV, and 267 (13.8%) as other modes of ventilation. At the start of study period, 16 patients (11.3%) were already on PSV, 98 (69.5%) were already on SIMV, and 27 (19.1%) were already on other modes of ventilation. General clinical characteristics and clinical outcomes were similar between the groups. However, the APACHE III scores were lower in patients who were classified as being on other modes of ventilation, and surgical patients were less frequently ventilated with SIMV (Online Appendix, eTable 1). We found a similar pattern according to the most used ventilation mode (Online Appendix, eTable 2).

Over the first 7 days, there was a progressive increase in the percentage of time spent on PSV. Overall, 39.8% of total ventilation moments were on PSV (median [IQR] duration of PSV, 61.0 [26.5–97.5] hours) and 47% were on SIMV (median [IQR] duration of SIMV 82.0 [23.5–119.0] hours) (Figure 1; Online Appendix, eTable 3). By Day 7, 63.4% of study patients were on PSV, 25.3% were on SIMV, and 9.1% were on other modes of ventilation.

Pressure support ventilation practice

The most common PS level was 10 cmH_2O (352/780) [45.1%] observations), followed by 12 cmH_2O (103/708) [13.2%] observations) and 5 cmH_2O (95/780 [12.2%] observations). There was little variation in PS level over time (mean coefficient of variation per patient, 10.7 ± 24.4%), with 37 of 114 patients (32.4%) having no change in PS level over the entire observation period (Figure 2; Online Appendix, eFigure 1 and eFigure 2).

Ventilatory variables during pressure support ventilation

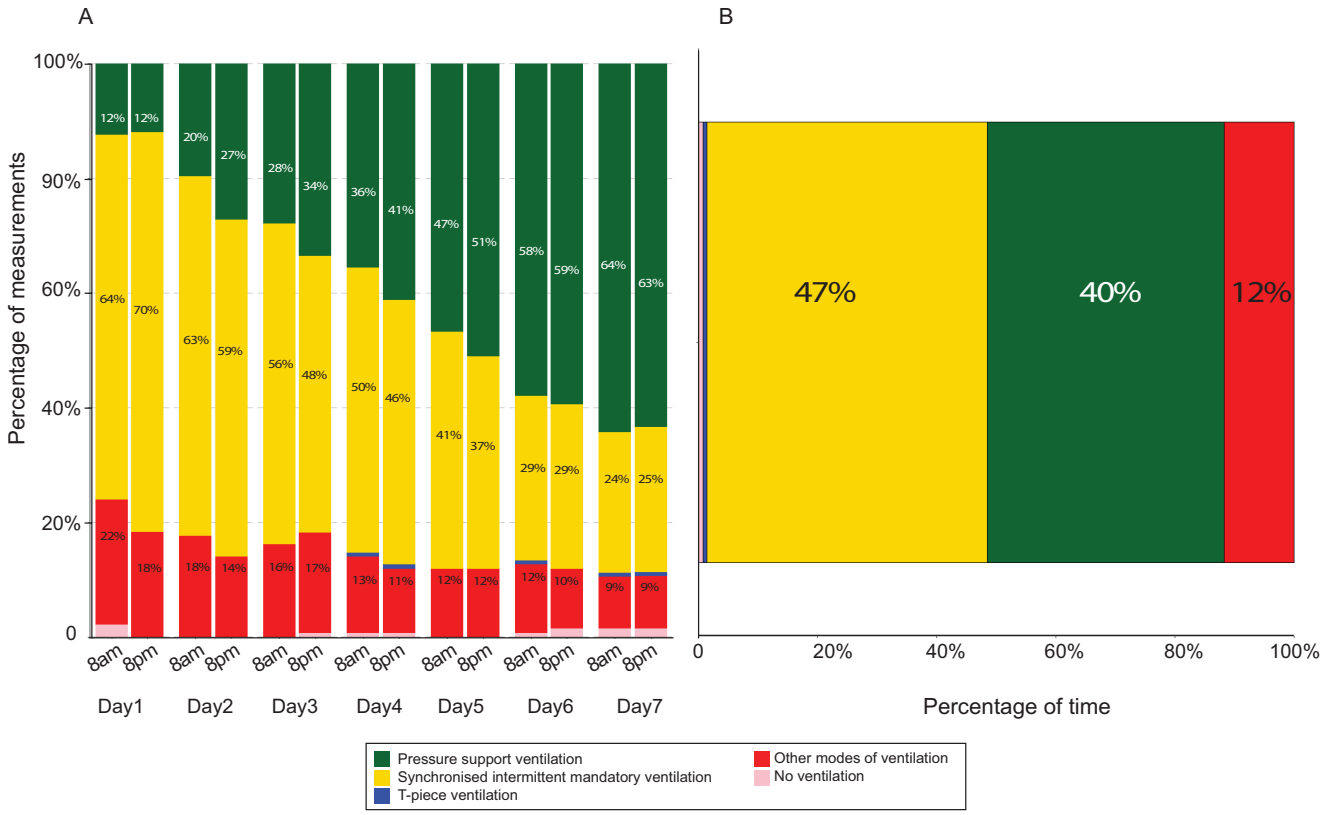
The median (IQR) Vt during PSV was 8.3 (7.0–9.5) mL/kg PBW, compared with 7.5 (7.0–8.3) mL/kg PBW with SIMV, and 7.7 (7.2–9.1) mL/kg PBW with other modes of ventilation ($P < 0.001$) (Table 2). Mean respiratory rate, minute ventilation and RSBI were higher during PSV (Table 2).

Table 1. Baseline characteristics and clinical outcomes of study patients

	All study patients (n = 143)*
Age, years	62.0 (50.0–70.5)
Men	94 (65.7%)
Body mass index, kg/m²	27.8 (24.2–32.0)
APACHE III score	68.0 (39.5–89.5)
Unplanned admission	111 (78.2%)
Surgical admission	57 (40.1%)
Admission diagnosis	
Cardiovascular	19 (13.4%)
Cardiovascular surgery	18 (12.7%)
Gastrointestinal	4 (2.8%)
Gastrointestinal surgery	11 (7.7%)
Haematological	3 (2.1%)
Musculoskeletal or skin	1 (0.7%)
Musculoskeletal surgery	2 (1.4%)
Neurological	15 (10.6%)
Neurological surgery	11 (7.7%)
Renal or genitourinary	1 (0.7%)
Renal or genitourinary surgery	1 (0.7%)
Respiratory	22 (15.5%)
Respiratory surgery	1 (0.7%)
Sepsis	14 (9.9%)
Trauma	11 (7.7%)
Trauma surgery	8 (5.6%)
Clinical outcomes	
ICU length of stay, days	15.0 (11.0–23.0)
Hospital length of stay, days	29.0 (18.0–51.2)
ICU mortality	39 (27.9%)
Hospital mortality	62 (44.3%)

APACHE = Acute Physiology and Chronic Health Evaluation. ICU = intensive care unit. * Data are median (interquartile range [quartile 25% to quartile 75%]) or number (percentage).

Figure 1. Percentages of measurements and percentages of total ventilation time that were under each ventilatory mode assessed*



* Panel A shows the percentages of measurements at 8am and 8pm on each study day that were under each specific ventilatory mode. Panel B shows the percentage of total ventilation time (168 hours) that was under each specific ventilatory mode.

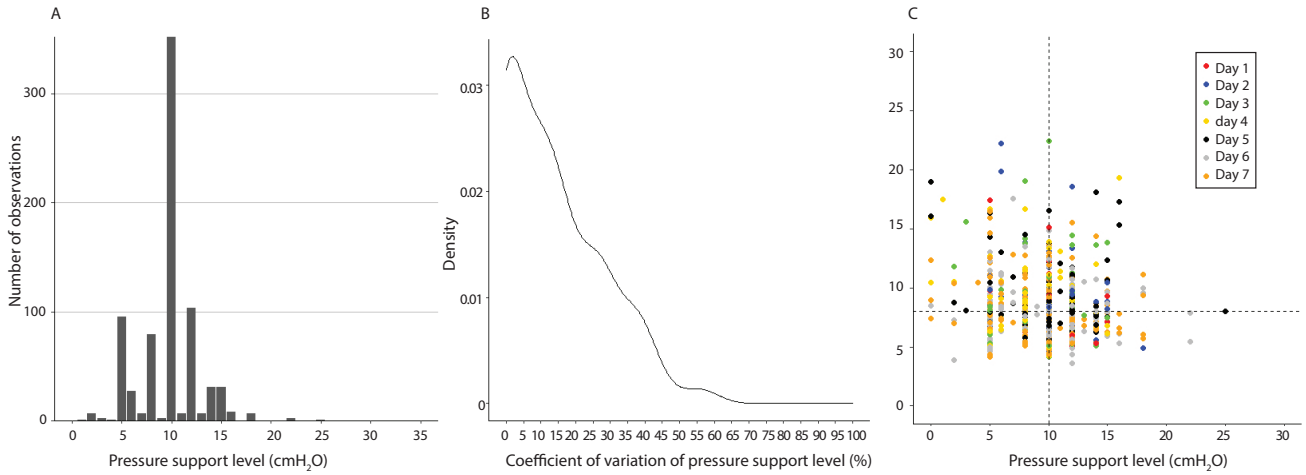
A comparison of moments with PSV versus moments with no PSV is shown online (Online Appendix, eTable 3 and eFigure 3). In total, 40% (315/784) of the measurements during PSV had a Vt ≥ 8 mL/kg PBW, compared with 25% (293/1151) during moments with no PSV (Figure 3). When Vt was > 8 mL/kg PBW, clinicians did not change the PS level in 75% of moments (247/331, they increased the PS level in 10% of moments (32/331), and they decreased the PS level in 16% of moments (52/331) (Online Appendix, eFigure 4).

During PSV, 53% (417/784) and 42% (326/784) of the measurements had an RSBI of ≤ 37 breaths/min/L and a respiratory rate of ≤ 17 breaths/min, respectively (Figure 3) implying likely over-assistance. Overall, in 78% of RSBI moments (269/346), clinicians did not change the PS level, in 9% (30/346) they increased it and in 14% (47/346) they decreased it (Online Appendix, eFigure 4). Comparisons of measurements in PSV, SIMV and other modes of ventilation are shown online (Online Appendix, eFigure 5). While an increase in PS level led to a decrease in Vt size (median difference, –0.13 [95% CI, –0.25 to –0.01]; $P = 0.025$), we found no relationship between RSBI or respiratory rate and PSV levels (Online Appendix, eFigure 6). However, the relationships between the changes in PS level and the Vt and RR measurements were highly variable (Online Appendix, eFigure 7).

Transition to PSV

After transition to PSV, there were increases in minute ventilation and absolute Vt (Online Appendix, eTable 4). After 24 hours of PSV, absolute Vt and Vt corrected for PBW were similar to values before transition. However, there were increases in respiratory rate, minute ventilation, RSBI and pH (Figure 4; Online Appendix, eTable 5 and eFigure 8) even though sedative doses did not change after transition. After transition to PSV, there was a significant increase in the number of patients receiving a Vt > 8 mL/kg PBW and having a low respiratory rate (Online Appendix, eFigure 9). However, after 24 hours, the Vt and respiratory rate patterns were similar to those in the moments immediately before transition.

Figure 2. Distribution of pressure support levels used, density data for coefficient of variation of pressure support level, and relationship between pressure support level and tidal volume*



PBW = predicted bodyweight. PSV = pressure support ventilation. * Panel A is a histogram showing pressure support level for all measurements during PSV during the first 7 days of ventilation. Panel B shows the density of the coefficient of variation (calculated as the standard deviation of the pressure support level divided by its mean) of pressure support level for all measurements during PSV during the first 7 days of ventilation and per patient. Panel C is a scatterplot of pressure support level and tidal volume size adjusted by PBW for all measurements during PSV in the first 7 days of ventilation.

Likely over-assistance

Among 122 patients exposed to PSV, the vast majority had at least one moment of likely over-assistance according to respiratory rate (94 patients [77.0%]) and RSBI (97 patients [79.5%]). Of 784 PSV moments, 326 (41.6%) were in the likely over-assistance range according to the respiratory rate and 411 (52.4%) according to the RSBI (Figure 3).

Sedation and arterial blood gases

The cumulative and mean daily doses of fentanyl and propofol were lower during moments on PSV than during moments not on PSV (Online Appendix, eTable 6 and eTable 7). While Fio_2 and $Paco_2$ levels were lower during moments on PSV, pH and HCO_3 levels were higher. Oxygenation parameters (Spo_2 levels and Pao_2/Fio_2 ratios) were similar.

Discussion

Key findings

We assessed the current practice of PSV in a cohort of patients in Australian ICUs who received prolonged invasive mechanical ventilation (more than 1 week). We found that clinicians applied PSV during 40.5% of the total ventilation moments, and that more than 60% of patients were exposed to PSV during the study period. The initiation of PSV resulted in a higher mean Vt, with 40% of the measurements under PSV showing a Vt of ≥ 8 mL/kg PBW, significantly more than with SIMV. In addition, the most common PS level by far was 10 cmH_2O, with little variation during the study period. Finally, likely over-assistance was evident in half of PSV moments, and PS level adjustment in response to this was uncommon.

Relationship to previous studies

To our knowledge, this is the first study of PSV practice in patients receiving prolonged invasive ventilation. However, more than 10 years ago, a single 1-day point prevalence study was performed in Australia and New Zealand and showed that PSV was used in 41% of patients.[15] This study did not report data on Vt or over-assistance during PSV. In contrast, a multicentre observational study that was conducted in 12 ICUs in the United States and published in 2018 showed that PSV was used in only 10% of patients, but it also provided no additional data on PSV use.[16] A multinational 1-day point prevalence study conducted in nine countries, which included 1638 patients from 412 ICUs across North America, South America and Europe, showed that PSV was used for maintenance ventilation in only 6% of patients.

If the above findings are representative, then the practice and choice of invasive mechanical ventilation mode is markedly different in Australia compared with the United States and perhaps elsewhere. It is unclear why overseas

Table 2. Ventilatory variables for study patients during moments of pressure support ventilation, synchronised intermittent mandatory ventilation, and other modes of ventilation

	Pressure support ventilation* (*n* = 784)	Synchronised intermittent mandatory ventilation* (*n* = 884)	Other modes of ventilation* (*n* = 267)	*P*†
Tidal volume, mL				
Mean per moment	533.9 (461.1–623.1)	501.9 (462.6–540.1)	500.0 (442.7–550.0)	0.035
Lowest	422.0 (374.2–500.0)	450.0 (400.0–493.0)	405.0 (355.5–467.5)	0.081
Highest	650.0 (531.2–800.0)	571.0 (500.0–650.0)	550.0 (501.5–659.5)	< 0.001
Tidal volume, mL/kg PBW				
Mean per moment	8.3 (7.0–9.5)	7.5 (7.0–8.3)	7.7 (7.2–9.1)	0.042
Lowest	6.5 (5.4–7.8)	6.6 (6.2–7.3)	6.6 (5.7–7.4)	0.714
Highest	10.2 (8.2–12.9)	8.5 (7.7–9.9)	9.2 (7.9–11.4)	< 0.001
PEEP, cmH_2O				
Mean per moment	6.7 (5.0–8.4)	6.8 (5.0–8.9)	8.0 (5.3–10.0)	0.169
Lowest	5.0 (5.0–8.0)	5.0 (5.0–6.0)	7.0 (5.0–8.5)	0.012
Highest	8.0 (5.0–10.0)	8.0 (5.0–10.0)	9.0 (6.0–10.5)	0.388
Pressure support level, cmH_2O				
Mean per moment	10.0 (8.5–11.6)	—	—	—
Lowest	10.0 (6.0–10.0)	—	—	—
Highest	11.5 (10.0–14.0)	—	—	—
Respiratory rate, breaths/min				
Mean per moment	18.8 (16.1–23.0)	16.8 (14.4–19.4)	16.5 (14.8–18.3)	< 0.001
Lowest	13.0 (10.2–17.0)	14.0 (12.0–16.0)	13.0 (12.0–16.0)	0.757
Highest	25.5 (20.0–30.0)	20.0 (17.0–23.0)	18.0 (16.5–24.0)	< 0.001
Minute ventilation, L/min				
Mean per moment	9.7 (8.2–11.8)	8.3 (6.9–10.2)	7.9 (6.9–9.7)	< 0.001
Lowest	7.0 (5.7–9.5)	6.8 (5.3–8.1)	5.9 (5.0–7.9)	0.008
Highest	12.6 (10.2–15.7)	10.0 (8.4–12.1)	9.3 (8.2–12.2)	< 0.001
RSBI, breaths/min/L				
Mean per moment	37.5 (28.9–53.3)	33.3 (28.9–39.6)	33.6 (30.0–41.0)	0.012
Lowest	21.3 (14.1–33.5)	25.2 (21.4–31.1)	24.9 (20.3–31.8)	0.078
Highest	53.7 (40.0–76.7)	41.3 (34.7–50.0)	44.4 (34.5–51.1)	< 0.001

PBW = predicted bodyweight. PEEP = positive end-expiratory pressure. RSBI = rapid shallow breathing index. * Every patient had 14 moments of measurement of ventilatory variables, and data are median (interquartile range [quartile 25% to quartile 75%]) of the aggregated mean, lowest and highest values per patient and per ventilatory mode at the moment of measurement. † *P* values reflect between-group comparisons.

ICUs appear to avoid PSV, while Australian ICUs appear to embrace it.[17] However, the recent PReVENT study, which allowed the use of PSV, found that PSV was applied to 20% of the patients in the first 3 days, implying growing use.[18] On the other hand, in these patients, it was impossible to achieve the target low Vt — a possible reason for the avoidance of this mode of ventilation in some, and perhaps many, ICUs.

Although the clinical impact of higher Vt during PSV on clinical outcomes has not been assessed, a large Vt size during PSV has been shown to decrease the neural inspiratory time and inspiratory efforts.[19] Moreover, a high PS level can: lead to overdistension, prolonged inspiratory time and increased patient–ventilator dys-synchrony;[12,20,21] stretch the diaphragm; and worsen ventilator-induced diaphragm dysfunction.[22] Our study showed that in 17%

Figure 3. Stacked bar plots showing different ranges of tidal volume, rapid shallow breathing index and respiratory rate according to use of pressure support ventilation

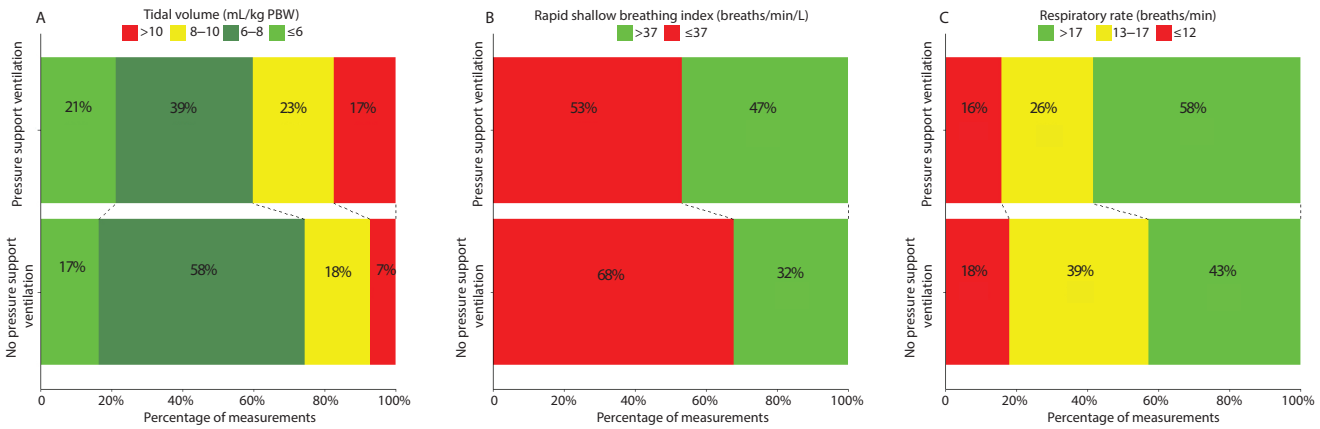
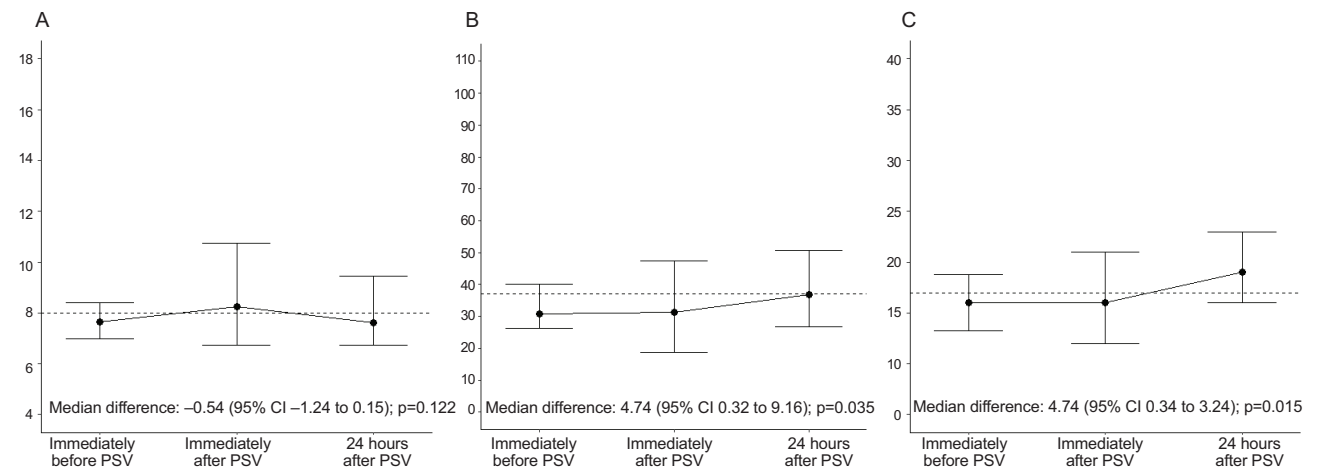


Figure 4. Tidal volume, rapid shallow breathing index and respiratory rate at moments immediately before, immediately after and 24 hours after transition to PSV*



PSV = pressure support ventilation. * Circles represent medians, and error bars represent 25% and 75% quartiles. Median differences and 95% confidence intervals were calculated using a mixed-effect quantile model considering a = 0.50 and an asymmetric Laplace distribution. *P* values were extracted after 1000 bootstrap samples and patients were included as a random effect.

of the measurements during PSV, Vt was ≥ 10 mL/kg of PBW. Despite this, the PS level of 10 cmH_2O appeared stereotypical, and was rarely adjusted, similar to what was seen in a previous study of patients ventilated for a shorter period.[23]

In a recent study of over-assistance during PSV — which was defined as the occurrence of a work of breathing level of < 0.3 J/L, or an incidence of ineffective inspiratory efforts of > 10%[14] — it was found that a respiratory rate of ≤ 17 breaths/min, or a RSBI of ≤ 37 breaths/min/L, accurately predicted over-assistance. The occurrence of such likely over-assistance was evaluated in a multicentre Australian study of patients receiving short-term PSV, where it occurred in 40–53% of the measurements.[23] In our study, we found a similar rate of likely over-assistance.

Implications of study findings

Our findings imply that PSV is common in patients receiving prolonged invasive ventilation in Australian ICUs, where it accounts for close to half of overall ventilation time in

the first 7 days of ventilation. Moreover, our data imply that the transition to PSV is associated with more patients experiencing higher Vt, and that PSV appears to be prescribed in a stereotypical way, with little adjustment. Finally, they imply that likely over-assistance occurs frequently during PSV.

Study strengths and limitations

To our knowledge, this is the first multicentre study describing the practice details of PSV applied to patients receiving prolonged ventilation in an ICU setting. It involved three metropolitan ICUs and two regional ICUs with wide varieties of diagnoses, and it likely represented the ventilation practice of more than 100 ICU specialists, fellows and senior residents with more than 2000 observations.

Our study has some limitations. It was performed in the state of Victoria and may not represent national practice. However, the use of ventilation modes was similar to the ventilation modes in a previous study conducted in Australia and New Zealand. Thus, our findings are likely to reflect Australian and New Zealand use of PSV in patients receiving prolonged ventilation.

In addition, we used a retrospective study design. However, we obtained documented ventilation data for 7 consecutive days, from different hospitals and from a wide variety of patient populations at different time intervals. The definitions of over-assistance were extrapolated from a previous study, but we found that Vt size in mL/kg of PBW was high, which is also consistent with likely over-assistance. Moreover, we used the term "likely" because we did not use oesophageal manometry to measure the work of breathing.

Conclusions

In patients receiving prolonged invasive ventilation in Australia, PSV appeared to account for almost half of mechanical ventilation time during the first 7 days. Moreover, it appears that about half of the patients who received PSV were exposed to large Vt and likely over-assistance. In moments of large Vt or likely over-assistance, there was little response by clinicians, with few changes in PS levels. These observations imply that PSV management could be improved. They also provide the epidemiological background needed to plan interventional studies aimed at optimising the quality of PSV.

Competing interests

No relevant disclosures.

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