Do we practise low tidal-volume ventilation in the intensive care unit? A 14-year audit

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Abbreviations

ALI	acute lung injury
APACHE	Acute Physiology and Chronic Health Evaluation
ARDS	acute respiratory distress syndrome
ARDSnet	acute respiratory distress syndrome network
BMI	body mass index
ICCA	IntelliSpace Critical Care and Anesthesia
IQR	interquartile range
LPV	lung-protective ventilation
LTVV	low tidal volume ventilation
MV	mechanical ventilation
P/F	PaO_2/FiO_2
PBW	predicted body weight
PCV	pressure-controlled ventilation
PEEP	positive end expiratory pressure
PIP	peak inspiratory pressure
SIMV	synchronised intermittent mandatory ventilation

ABSTRACT

Background: Low tidal volume ventilation (LTVV) has been shown to reduce mortality of patients with acute lung injury (ALI) but uptake by clinicians has been low. Recent studies have shown that LTVV results in survival benefit at 24 months after discharge and, importantly, benefits patients without ALI.

Objective: To determine adherence to LTVV in patients on mechanical ventilation (MV).

Design, setting and participants: Retrospective analysis of ventilator settings recorded within the clinical information system of a 15-bed general ICU in a tertiary referral hospital, between 1 January 2000 and 31 May 2013.

Methods: Analysis of mandatory MV with volume or pressure control.

Main outcome measures: Adherence to LTVV (≤ 6.5 mL/kg predicted body weight [PBW]).

Results: We studied 4923 patients with a median age of 66 years (interquartile range [IQR], 57–74 years), and a median Acute Physiology and Chronic Health Evaluation II score of 16 (IQR, 13–19). Included were 3486 men (70.8%), and 3386 (66.8%) had undergone cardiac surgery. There were 249 450 ventilator measurements, with a median per patient of 75 measurements (IQR, 17–255 measurements). The median tidal volume was 8.15 mL/kg PBW (IQR, 7.15–9.34 mL/kg PBW) for an adherence of 13.4%. Independent factors associated with adherence were sex, high inspiratory pressures, high positive end expiratory pressure and low PaO_2/FiO_2 ratio.

Conclusion: Adherence to LTVV in a general cohort of ICU patients was low, but it was better in patients with more severe lung disease. Overestimation of PBW may have contributed to our findings. Regular auditing of LTVV adherence might be considered a clinical indicator of good MV practice.

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Mechanical ventilation (MV) remains a primary indication for admission to an intensive care unit, and its safe application to critically ill patients is the sole responsibility of intensivists in Australia and New Zealand. Since the publication of the acute respiratory distress syndrome (ARDS) network (ARDSnet) article in 2000 showing the benefits of low tidal volume ventilation (LTVV) in patients with ARDS,[1] we have become more aware of the morbidity associated with our ventilator settings. The study showed that reducing tidal volume from 12 mL/kg predicted body weight (PBW) to 6 mL/kg PBW led to a 25% relative reduction in hospital mortality. Despite this publication, we know that ICUs have been slow to adopt this new knowledge and that large tidal volumes are still used.[2,3]

In 2012, Needham and colleagues published a study involving 13 ICUs in Baltimore, Maryland.[4] Of the 485 patients on MV with acute lung injury (ALI), 41% experienced lung-protective ventilation (LPV), defined as a tidal volume ≤ 6.5 mL/kg PBW and plateau pressure ≤ 30 cm H_2O. Increased ICU adherence to LPV resulted in significant reduction in mortality at 2 years. A 2013 study of intraoperative protective ventilation involved patients at increased risk of pulmonary complications undergoing elective abdominal surgery who were randomised to 6–8 mL/kg or 10–12 mL/kg.[5] The group assigned to low tidal volume had fewer complications overall (10.5% v 27.5%), less need for postoperative ventilation (5% v 17%) and a shorter mean length of hospital stay (by 2.45 days).

Despite the apparent importance of tidal volume regulation in MV, quality programs for patients on MV, such as the "ventilator bundle", do not include any targets for tidal volume or ventilator settings.[6]

Table 1. Characteristics of patients

Characteristic	Data ($N = 4923$)
Age, years*	66 (57–74)
Men†	3486 (70.8%)
Height, cm*	170 (162–176)
Weight, kg*	80 (70–91)
Predicted body weight, kg*	66 (57–72)
BMI, kg/m^2*	27.8 (24.7–31.4)
Length of ICU stay, days*	3 (2–5)
Died in ICU†	329 (6.6%)
Died in hospital†	553 (11.1%)
Origin†	
Operating room	3881 (76.6%)
Emergency department	339 (6.7%)
Ward	300 (5.9%)
Interhospital transfer	548 (10.8%)
ICU category†	
Cardiac surgery unit	3502 (69.1%)
General	1549 (30.6%)
Postoperative monitoring	17 (0.3%)
Clinical unit†	
General medicine	432 (8.5%)
Special medicine	423 (8.4%)
General surgery	187 (3.7%)
Special surgery	4026 (79.4%)
APACHE II score*	16 (13–19)
Most common reasons for ICU admission†	
Coronary bypass surgery	2141 (42.3%)
Cardiac valve surgery	793 (15.6%)
Cardiac valve and bypass surgery	452 (8.9%)
Septic shock	164 (3.2%)
Cardiac arrest	152 (3.0%)
Cardiogenic shock	116 (2.3%)
Subarachnoid haemorrhage	70 (1.4%)
Bowel perforation	66 (1.3%)
Other postoperative cardiac surgery	65 (1.3%)

BMI = body mass index. ICU = intensive care unit. APACHE = Acute Physiology and Chronic Health Evaluation. * Median (interquartile range). † *n* (%).

We undertook our study to document our compliance with LTVV in a general ICU and to examine factors that were associated with better adherence to LTVV.

Methods

We conducted our study in the ICU of St Vincent's Hospital, Melbourne, which is a 450-bed tertiary referral hospital affiliated with the University of Melbourne. There is a single ICU with 15 beds through which 1200–1350 patients pass each year. About 40% of these patients have undergone cardiac surgery and 73% need MV. Our ICU has a clinical information system (IntelliSpace Critical Care and Anesthesia [ICCA], Philips) into which all clinical observations and laboratory data are entered or imported. The ICU also maintains a database of patient information (eg, demographics, severity-of-illness scores and clinical outcomes) which can be linked to the ICCA database and to hospital administrative databases. The study was undertaken as a quality assurance project and was approved by the hospital human research ethics committee.

We included patients who were admitted to the ICU and mechanically ventilated with pressure-controlled ventilation (PCV) or synchronised intermittent mandatory ventilation (SIMV) between 1 January 2000 and 31 May 2013. We excluded breaths taken during pressure support ventilation. For a patient to be included, their height had to be recorded so we could calculate their PBW.[1]

Data on these ventilated patients were extracted from the sources described above to provide information on demographic factors (age, sex, height and weight), admission parameters (origin, clinical unit and Acute Physiology and Chronic Health Evaluation [APACHE] diagnostic category[7]), severity of illness (APACHE II score[8]) and clinical outcome. Ventilator settings are recorded hourly in the clinical information system and parameters extracted included airway type (endotracheal or tracheal tube), mode of ventilation (PCV or SIMV), tidal volume, respiratory rate, peak pressure, positive end expiratory pressure (PEEP) and minute ventilation. FiO_2 and PaO_2 were also recorded. From these raw data, PBW and PaO_2/FiO_2 (P/F) ratio were calculated. An adherent tidal volume was defined as a volume $\leqslant$ 6.5 mL/kg PBW;[4] values 8.0 mL/kg PBW are also reported.

The data are expressed as means and SDs, or medians and interquartile ranges (IQRs), depending on the variable's distribution. Categorical variables are reported as numbers and percentages. Comparisons between continuous variables involved the Mann–Whitney *U* test and categorical variables were compared using the Fisher exact or χ^2 tests. Multivariable logistic regression was used to explore associations between clinical factors and adherence to LTVV. Data were analysed with Stata, version 13 (StataCorp) and statistical significance was set at $P < 0.05$

Results

In the study period, there were 15 680 distinct admissions to our ICU, and 75.3% of these patients needed MV. For 5068 of these admissions (which were for 4923 patients), the patient's height was recorded, enabling calculation of PBW. The patient characteristics are shown in Table 1.

During these 5068 admissions, there were 249 450 distinct recordings of ventilation parameters, modes of ventilation and airway type (see Table 2). Patients had significant gas exchange impairment, as seen by the percentage of

Table 2. Characteristics of mechanical ventilation

General characteristics	Data (n = 249 450)
Airway type, endotracheal tube*	203 066 (81.4%)
Mode of ventilation, PCV*	126 560 (50.7%)
Recordings per admission†	75 (17–255)
Observations > 12 hours after admission*	180 701 (72.4%)
Ventilator characteristics	
Tidal volume, mL†	506 (450–576)
Tidal volume/predicted body weight, mL/kg†	8.15 (7.15–9.34)
Tidal volume ⩽ 6.5 mL/kg*	33 365 (13.4%)
Tidal volume ⩽ 8.0 mL/kg*	114 928 (46.1%)
Respiratory rate, breaths/min†	17 (14–20)
PIP, cmH_2O†	27 (22–31)
PIP > 30 cmH_2O*	65 018 (26.1%)
PEEP, cmH_2O†	8 (5–10)
PEEP > 10 cmH_2O*	42 948 (17.2%)
Minute ventilation, L/min†	8.5 (7.1–10.3)
P/F ratio†	253 (126–365)
P/F ratio < 300*	151 880 (60.9%)
P/F ratio < 200*	99 811 (40.0%)
Period (%)	
2000–2005	34.6%
2006–2009	40.4%
2010–2013	25.0%

PCV = pressure-controlled ventilation. PIP = peak inspiratory pressure. PEEP = positive end expiratory pressure. P/F = PaO_2/FiO_2. * n (%). † Median (interquartile range).

recordings in which the P/F ratio was < 300 and < 200, PEEP levels were > 10 cmH_2O, or peak inspiratory pressures (PIPs) were > 30 cmH_2O.

The percentage of tidal volume measures ⩽ 6.5 mL/kg was 13.4%, and 46.1% of tidal volumes were ⩽ 8.0 mL/kg.

Several factors were assessed to determine their impact on adherence to ⩽ 6.5 mL/kg PBW and ⩽ 8.0 mL/kg PBW targets, including sex, age, body mass index (BMI), early or late ventilation, type of ventilation and severity of lung function impairment (recordings in which PIP was > 30, PEEP > 10 cmH_2O and P/F < 200). All these factors were significantly associated with tidal volume compliance in univariate analysis (see Table 3).

The independent effects of these factors were investigated with logistic regression (see Table 4). Adherence to 6.5 mL/kg settings was more likely in men, patients with worse lung function, patients with PCV ventilation and in the most recent time period. Factors associated with non-adherence to 6.5 mL/kg settings were increasing age, higher BMI, higher minute ventilation requirements and transfer from the operating theatre after cardiac surgery.

Discussion

Key findings

With the benefit of an ICU clinical information system, we undertook a 14-year audit of MV in our ICU. We found that overall compliance with LTVV, according to our definition, was poor (13.4% of settings were compliant) although nearly half the settings (46.1%) had tidal volumes ⩽ 8.0 mL/kg. Patients with worse lung function tended to have better adherence to LTVV but women, patients with higher BMIs and patients returning from operating theatres after cardiac surgery had less adherence to LTVV. Adherence was better as time on ventilation in the ICU increased.

Relationship to previous studies

Several studies have considered patients with ALI or ARDS and these diagnoses were based on the original definitions for lung injury.[9] Young and colleagues reported adherence to LTVV in 154 patients before publication of the ARDSnet article and 146 patients after publication; average tidal volumes were 12.3 mL/kg before and 10.6 mL/kg after publication; and adherence to ⩽ 8.0 mL/kg was 5% before and 16% after publication.[3] Kalhan and colleagues found better adherence in a cohort of patients between 2000 and 2002.[2] In the 88 patients, most had volumes ⩽ 8.0 mL/kg throughout the study period but on Day 2, 39% received volumes ⩽ 7.5 mL/kg and 24% received volumes ⩽ 6.5 mL/kg. These percentages are similar to our findings, with corresponding rates on Day 2 of 47.3% (⩽ 8 mL/kg) and 12.2% (⩽ 6 mL/kg).

Several articles have looked into factors that might limit LTVV. Denison and Rubenfeld surveyed ICUs to assess the barriers to implementing LTVV.[10,11] Attitudes and behaviours of clinicians were consistently found to be barriers, including unwillingness to relinquish ventilator control, concern about patient comfort, hypercapnia or acidosis, and probably under-recognition of ALI and ARDS. Lack of knowledge of the benefits of LTVV was also a barrier, especially in more junior staff. In a later report, Umoh and colleagues noted that adherence was significantly improved with a written protocol for LTVV.[12]

Our study concentrated on patient factors and several were identified. An overestimation of PBW was the likely reason for poorer adherence to LTVV in women and in patients with an elevated BMI. A second group comprised cardiac surgery patients whose initial ventilation was traditionally set by the anaesthetists to 10 mL/kg actual body weight. The third group of factors might be called "severity of lung disease", in which adherence was better in patients with higher PIP and PEEP, lower P/F ratios, and values obtained after 12 hours of MV. The fourth factor was calendar year, with greater adherence between 2010 and 2013. A fifth factor was minute ventila-

Table 3. Comparison of factors associated with adherence to tidal volumes ⩽ 6.5 mL/kg PBW and ⩽ 8.0 mL/kg PBW

	Tidal volume, % (*P*)	
Factor	⩽ 6.5 mL/kg	⩽ 8.0 mL/kg
Sex		
Men	16.2% (< 0.001)	54.6% (< 0.001)
Women	7.6%	28.9%
Ventilation stage		
Early (⩽ 12 hours)	7.9% (< 0.001)	43.3% (< 0.001)
Late (> 12 hours)	15.4%	47.1%
Peak airway pressure > 30 cmH_2O		
No	10.9% (< 0.001)	44.3% (< 0.001)
Yes	20.4%	50.9%
PEEP > 10 cmH_2O		
No	11.5% (< 0.001)	44.4% (< 0.001)
Yes	16.3%	48.7%
P/F ratio < 200		
No	12.9% (< 0.001)	45.6% (< 0.001)
Yes	14.1%	46.7%
Age group (years)		
< 35	29.9% (< 0.001)	74.9% (< 0.001)
35–44	18.8%	56.6%
45–54	20.3%	54.9%
55–64	10.1%	42.9%
65–74	11.7%	43.9%
⩾ 75	7.3%	34.3%
BMI group		
< 20	21.0% (< 0.001)	52.8% (< 0.001)
20–24	22.4%	59.7%
25–29	10.6%	42.7%
30–34	8.8%	41.1%
35–39	5.6%	27.3%
⩾ 40	11.4%	40.6%
Ventilation mode		
SIMV	44.2% (< 0.001)	7.9% (< 0.001)
PCV	47.9%	15.4%
Cardiac surgery		
No	16.5% (< 0.001)	50.4% (< 0.001)
Yes	9.5%	40.8%

PBW = predicted body weight. PEEP = positive end expiratory pressure. P/F = PaO_2/FiO_2. BMI = body mass index. SIMV = synchronised intermittent mandatory ventilation. PCV = pressure-controlled ventilation.

Table 4. Multivariate predictors of adherence to tidal volumes ⩽ 6.5 mL/kg PBW*

Predictor	Odds ratio (95% CI)	*P*
Men	3.17 (3.08–3.27)	< 0.001
Late ventilation (> 12 hours)	1.68 (1.62–1.74)	< 0.001
PIP > 30 cmH_2O	2.09 (2.03–2.15)	< 0.001
PEEP > 10 cmH_2O	1.16 (1.08–1.15)	< 0.001
Minute ventilation > 10 L/min	0.29 (0.28–0.30)	< 0.001
Age	0.97 (0.97–0.97)	< 0.001
Body mass index	0.94 (0.94–0.94)	< 0.001
After cardiac surgery	0.93 (0.89–0.96)	< 0.001
PCV	2.17 (2.11–2.24)	< 0.001
P/F ratio < 200	1.12 (1.09–1.15)	< 0.001
Period (reference, 2000–2005)		
2006–2009	0.95 (0.92–0.98)	< 0.01
2010–2013	1.11 (1.07–1.16)	< 0.001

PBW = predicted body weight. PIP = peak inspiratory pressure. PEEP = positive end expiratory pressure. PCV = pressure-controlled ventilation P/F = PaO_2/FiO_2. * Area under receiver operating characteristic curve = 0.76.

tion; adherence was worse when minute ventilation > 10 L/min, suggesting that clinicians were having difficulty maintaining pH and $PaCO_2$. Kalhan and colleagues also noted better adherence in patients with more severe lung disease (lower PaO_2 and lower compliance) and later days of MV (Day 7 v Day 2) but not with sex or age.[2] In contrast, Fernandez and colleagues found that, in 429 patients undergoing prolonged abdominal surgery, high tidal volumes (> 10 mL/kg PBW) were more common in women, patients with a BMI > 30 kg/m^2 and patients < 165 cm tall.[13] Umoh and colleagues considered sex, serum bicarbonate levels, nurse : patient ratio, Charlson comorbidity index and a written ARDS protocol, and found that a written ARDS protocol was significant in a multivariable analysis.[12]

Implications of findings

Recent publications highlight the importance of LTVV in patients with lung injury, in ICU patients without ALI and in patients undergoing routine surgery. Needham and colleagues studied a cohort of 485 patients with ALI and found that better adherence to LTVV (⩽ 6.5 mL/kg) resulted in better 2-year survival, taking into account a range of potentially confounding factors.[4] The magnitude of this benefit was seen in a mortality risk reduction of 4% for a standard patient with 50% ventilator adherence compared with 7.8% reduction for 100% adherence. They also showed an 18% relative increase in mortality for each 1 mL/kg PBW increase in average tidal volume. These findings are more evidence that patients with lung injury require LTVV.

Gajic and colleagues reported on 332 patients undergoing MV for more than 48 hours who did not have ALI on admission to the ICU,[14] of whom 24% developed lung injury within 5 days. Tidal volumes > 6 mL/kg PBW were associated with more frequent development of lung injury. A recently published meta-analysis of LTVV in patients without ARDS shows that LTVV leads to less lung injury and reduced mortality, and that lung infections and lengths of stay are also reduced.[15]

Ventilation outside the ICU has been studied. Futier and colleagues compared LTVV (6–8 mL/kg PBW) with non-protective tidal volume ventilation (10–12 mL/kg PBW) in 400 adult patients at intermediate risk of pulmonary complications undergoing major abdominal surgery.[5] The LTVV patients had fewer complications in the first 7 days after surgery, needed less ventilation for acute respiratory failure and had shorter lengths of stay. A review of all these studies has been published recently.[16]

These articles indicate that LTVV is beneficial in the longer term for patients with lung injury but should probably be the standard treatment for most patients undergoing MV unless higher tidal volumes are required. Higher volumes may be necessary in situations such as metabolic acidosis or for patient comfort, and when changes in respiratory frequency cannot compensate. If LTVV were the standard, the barriers noted above of underdiagnosis of lung injury and doctors hesitant to order LTVV would no longer exist. However, our results show that even when LTVV is prescribed, it may not be implemented by staff, perhaps partly due to overestimation of body weight. There are often comments that height cannot be easily measured in recumbent patients but the measurement of demi-span with extrapolation to height is simple and accurate.[17,18]

Strengths and limitations

Our study involved all patients coming through a general ICU over several years spanning the period from when the ARDSnet paper was published to current clinical practice. The presence of our ICCA has meant that complete and accurate data were available for analysis and could easily be cross-referenced with patient information. However, not all patients had their height recorded so PBW could not be calculated in about 45% of patients on MV. This was a single-centre study, so extrapolation to other patient populations should be done cautiously.

Conclusion

The evidence of benefits of LTVV on patient outcomes continue to accumulate and there is evidence that LTVV should be routine for all patients on MV. As with previous studies, our adherence to LTVV was low, which highlighted the importance of calculating the PBW for all patients needing ventilation. Adherence to agreed ventilation strategies such as LTVV should be included in clinical indicators of intensive care and will become simpler with the ever-increasing use of clinical information systems.

Competing interests

None declared.

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