Predicted body weight during mechanical ventilation: using arm demispan to aid clinical assessment

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ABSTRACT

Introduction: Recent research suggests an association between the development of acute lung injury (ALI) and mechanical ventilation with tidal volumes > 6 mL per kg of predicted body weight (BW). Specific subgroups (women and obese patients) may be at risk of unintentional delivery of excessive tidal volumes. We conducted a prospective audit of delivered tidal volumes (mL/kg) calculated using recorded BW and compared these to volumes calculated using predicted BW.
Participants and setting: Patients requiring controlled mechanical ventilation admitted to a mixed intensive care unit in October 2006 were eligible. Exclusion criteria were ALI on admission or no recorded BW (defined as a weight measured by scales or a dietitian-estimated weight) for the current admission.
Methods: Arm demispan was used to calculate height, and predicted BW was derived using ARDSNet formulas. Hourly Day 1 tidal volumes were downloaded from the medical record, and the mean for each patient was calculated. Volumes (mL/kg) were calculated using predicted and recorded BW. Data are presented as mean (SD) or median (interquartile range) depending on normality. The Mann–Whitney rank sum test was used for comparisons.
Results: 34 patients were studied (20 men) with a mean age of 60.6 (SD, 13.3) years and mean APACHE II score of 19.5 (SD, 6.1). Predicted BW was lower than recorded BW (69.0 [61.0–74.8] v 75 [65–85] kg; $P < 0.05$). Median tidal volumes (mL) were higher for men than women (552 [530–586] v 474 [424–500]; $P < 0.01$). Tidal volumes expressed as mL/kg were higher when calculated from predicted BW than from recorded BW (7.8 [7.3–8.3] v 7.2 [6.3–7.9]; $P < 0.05$). Volumes calculated using predicted BW were higher among women than men (8.2 [7.8–8.7] v 7.5 [6.8–8] mL/kg; $P < 0.05$). The difference in volume between the sexes using recorded weight was not significant (7.5 [6.6–8.6] v 6.9 [6.2–7.8] mL/kg; $P = 0.42$).
Conclusion: Predicted BW was significantly less than recorded BW. Consequently, larger tidal volumes were delivered on a mL/kg basis when calculated using predicted BW than recorded BW. This was particularly so for women, who received higher volumes than men when using predicted BW. Calculating predicted BW using demispan as a surrogate marker of height is a cheap, easy and non-invasive tool for clinical assessment; its use in the ICU may result in the delivery of more appropriate tidal volumes.

Crit Care Resusc 2008; 10: 9–14

The impact of delivered tidal volumes currently receives little attention during a busy ward round of critically ill patients. However, a retrospective review of 332 ventilated patients without acute lung injury (ALI) on admission found an increased risk of ALI developing with mean tidal volumes above 6 mL per kg of predicted body weight (BW): for every additional 1 mL/kg over 6 mL/kg, the odds ratio of developing ALI increased by 1.3.[1] As expected, patients who developed ALI required longer periods of mechanical ventilation and were more likely to die in the ICU. In addition, analysis by sex found women were ventilated with higher tidal volumes and were more likely to develop ALI than men.[1]

A follow-up study (also a retrospective analysis) assessed 3261 patients and again found an association between initial ventilation volumes and the development of ALI.[2] Patients were classified as those receiving high tidal volume ventilation (defined as volumes greater than 700 mL) or normal ventilation. Acute respiratory distress syndrome (ARDS) developed in 6% of patients without ARDS on admission who were ventilated for more than 48 hours, and the odds ratio for developing ARDS with exposure to high tidal volumes was 2.6. The development of ARDS was associated with increased hospital mortality: 62% of patients with ARDS died in hospital, compared with 32% of critically ill patients without ARDS.[2]

Together, these studies suggest an association between median tidal volumes delivered during critical illness and development of ALI, which is associated with adverse outcomes. The smaller study also suggested a benefit of using predicted BW rather than recorded BW to guide ventilation volumes. The possible benefit of using predicted BW to guide ventilation was also seen in a retrospective secondary analysis of the ARDSNet low-volume ventilation data.[3] O'Brien et al compared patients with normal body mass index (BMI) entered in the ARDSNet trial and those who were overweight or obese, finding no increase in mortality for the latter. Obese patients received significantly higher tidal volumes (as mL/kg predicted BW) than patients with normal BMI at enrolment. The authors emphasised that, once patients were enrolled in the trial, they received standardised, protocol-driven ventilation calculated on predicted BW rather than recorded BW, and hypothesised that appropriate tidal volumes using predicted BW may have been responsible for the similar mortality rates.

Table 1. Characteristics of patients in the study

Characteristic	Men	Women
Number of patients	20	14
Age (years): mean (SD)	63.5 (49.2–70.5)	68.5 (60–74)
APACHE II score: mean (SD)	16.5 (14–21)	19.0 (14–25)
Predicted body weight (kg) (calculated from demispan): median (IQR)	74.8 (71.6–75.4)	59.2 (52.4–62.2)
Recorded body weight (kg) (actual or dietitian's estimate): median (IQR)	80.0 (72.5–86.5)	65.0 (56.0–70.0)

IQR = interquartile range.

Acceptance of low-volume ventilation into clinical practice is far from uniform, even for ARDS.[4-6] Appropriate ventilation settings for patients without ALI are even more contentious. The only data on volumes currently administered in non-ALI come from a cross-sectional study in the Americas, Spain and Portugal, where patients without ALI were ventilated with a median tidal volume of 9 mL/kg.[7] The approach among Australasian clinicians has not been assessed.

The two studies by Gajic et al[1,2] did demonstrate an association between low-volume ventilation and improved outcomes in patients without ALI on admission. However, this association must be validated in prospective studies before a causal relationship is confirmed.

While awaiting the results of prospective studies, we undertook an audit to quantify our current approach to median volumes delivered in patients without ALI. This was a non-interventional, observational study that aimed to improve understanding of the current median volumes delivered to critically ill patients without ALI in a standard ICU. We also compared predicted BW, calculated using arm demispan, with recorded BW, which is traditionally used to calculate weight-related variables. Both before and during the audit, non-ALI patients were ventilated using a spontaneous supported mode if possible and, if not possible, a controlled mode with peak pressures less than 30 cmH_2O. Previously, we gave little consideration to the volume administered in the absence of ALI. However, following the publication of the results of Gajic et al, it seemed prudent to improve our understanding of the volumes delivered.

During this audit, standard ventilation was continued with simultaneous assessment of predicted BW and documentation of recorded BW from the notes (usually from a dietitian's estimate). We then compared predicted BW to recorded BW and retrospectively calculated median volumes delivered as both mL per kg predicted BW and mL per kg recorded BW.

Our null hypothesis was that predicted BW was equal to recorded BW in critically ill, ventilated patients, and ipso facto that the median tidal volume calculated using predicted BW was equal to tidal volume calculated using recorded BW in patients without ALI. If Gajic et al's original observation is proven (that high tidal volume ventilation in patients without ALI is harmful), it will become even more important to have a precise tool for calculating body weight in the critically ill.

Methods

The study was conducted at St Vincent's Hospital, Melbourne, Victoria, a 400-bed tertiary referral hospital associated with the University of Melbourne. It has a single, mixed ICU, which admits 1100–1200 patients per year.

As this was an audit of current practice, ethics approval was not required. Patients were screened in October 2006 and were included if they were undergoing mechanical ventilation on a mandatory mode. Because of the focus on patients without ALI, patients with a PaO_2/FIO_2 ratio < 300 were excluded. Patients with no recorded BW were also excluded before analysis. Recorded BW was defined as a weight measured by scales or a dietitian-estimated weight recorded for the current admission.

The demispan was taken as a surrogate for height. Demispan was measured from the sternal notch to the root of the ring finger on the left hand[8] using a standard tape measure. The duty intensivists were unaware of the demispan measurement, and predicted BW was calculated only at analysis to limit bias. Height was calculated in centimetres:

Height (males) = (1.40 × demispan [cm]) + 57.8; or

Height (females) = (1.35 × demispan [cm]) + 60.1.

Predicted BW was then calculated from height using the standard formulas from the ARDSNet study:[9]

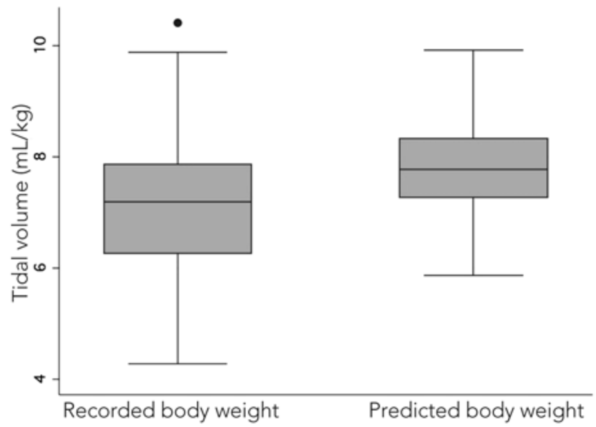
Predicted BW (males) = 50 + 0.91 (cm of height –152.4); or

Predicted BW (females) = 45.5 + 0.91 (cm of height –152.4).

Patients were ventilated using a non-volume controlled mode with a peak pressure of 30 cmH_2O or less, as per standard unit practice. Tidal volumes for the first day of ventilation were downloaded hourly from the medical records into our database, and the mean for each patient was calculated.

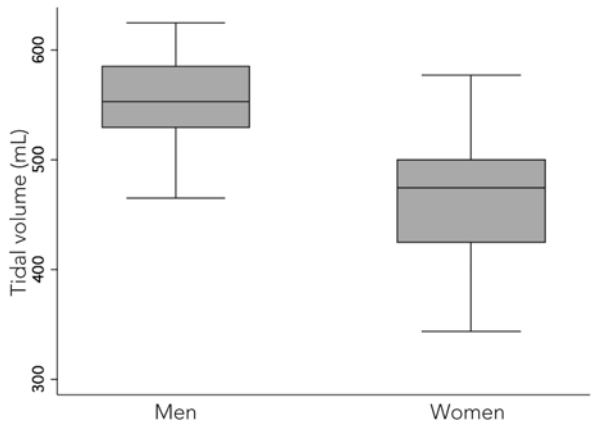
The data are presented as mean (SD) or median (interquartile range), depending on normality. The Mann–Whitney rank sum test was used for comparisons, with $P < 0.05$ taken to signify statistical significance. Analysis was performed using Stata version 9.2 (StataCorp, College Station, Tex, USA).

Figure 1. Tidal volumes calculated from recorded and from predicted body weight



Tidal volumes calculated from predicted body weight were greater than those calculated from recorded body weight (7.8 [7.3–8.3] v 7.2 [6.3–7.9]; P < 0.05).

Figure 2. Tidal volumes, by sex



Results

Forty-five patients were eligible for the study, but no record of body weight could be found in the patient notes for 11, leaving 34 patients (20 men and 14 women) in the study. They had a mean age of 60.6 years (SD, 13.3 years) and mean APACHE II score of 19.5 (SD, 6.1). Their characteristics are shown in Table 1. Predicted BW was lower than recorded weight (median [IQR], 69.0 kg [61.0–74.8] v 75 kg [65–85]; $P < 0.05$). This difference was also seen when patients were grouped by sex, with a significant difference for men (74.8 [71.6–75.4] v 80.0 [72.5–86.5]; $P < 0.05$) and a trend towards a difference for women (59.2 [52.4–62.2] v 65.0 [56.0–70.0]; $P = 0.17$).

It followed that the volumes calculated using predicted BW and recorded BW also differed. Mean tidal volumes (mL/kg) calculated from predicted BW were greater than those calculated from recorded BW (7.8 [7.3–8.3] v 7.2 [6.3–7.9]; $P < 0.05$; Figure 1).

When no adjustment was made for weight, men received larger tidal volumes than women (Figure 2). There was no difference in volumes delivered (mL/kg) between women and men using recorded BW (7.5 [6.6–8.6] v 6.9 [6.2–7.8]; $P = 0.42$). However, when volumes were calculated using predicted BW, women were ventilated at higher volumes than men (8.2 [7.8–8.7] v 7.5 [6.8–8.0]; $P < 0.05$; Figure 3 and Table 2).

Discussion

This audit found that recorded BW was greater than predicted BW, and that median tidal ventilation volumes delivered to patients calculated as mL/kg predicted BW were greater than tidal volumes expected from recorded BW. Women tended to receive higher tidal volumes[5] when calculated as mL/kg predicted BW than men. This may reflect a greater tendency to overestimate weight in women than in men. Alternatively, it may reflect the delivery of tidal volumes with little regard for weight as long as a target plateau pressure is not exceeded, resulting in higher volumes on a mL/kg basis among women, who tend to weigh less than men. A combination of these two factors is likely to be responsible for the observed difference between the sexes. These findings may have implications for routine mechanical ventilation, as discussed below.

Ventilator-associated lung injury was first demonstrated in animal models.[10,11] In 1988, Dreyfuss et al demonstrated that high-volume ventilation caused permeability pulmonary oedema and structural abnormalities in normal rat lung.[12] Results were similar in rabbits and lambs.[13,14] Human

Figure 3. Tidal volumes calculated from recorded and from predicted body weight, by sex

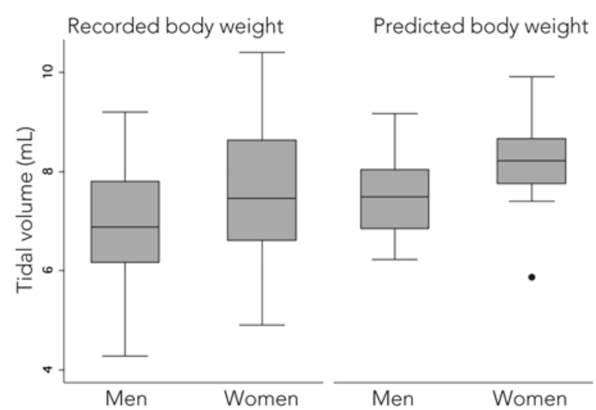


Table 2. Comparison of median tidal volumes (IQR) calculated from predicted and recorded body weights

		Tidal volume (mL/kg)	
	Tidal volume (mL)	From recorded weight	From predicted weight
All	533 (483–574)	7.8 (7.3–8.3)*	7.2 (6.3–7.9)*
Men	553 (530–586)†	7.5 (6.8–8.0)‡	6.9 (6.2–7.8)
Women	475 (425–500)†	8.2 (7.8–8.7)‡	7.5 (6.6–8.6)

IQR = interquartile range.
* $P < 0.05$ for comparison between predicted and recorded body weights.
† $P < 0.01$ for comparison between men and women.
‡ $P < 0.05$ for comparison between men and women.

studies of ventilation strategies in ventilator-associated lung injury initially focused on effects of delivered volumes and airway pressures in patients with pre-existing ALI or ARDS. A randomised multicentre study of low-volume versus high-volume ventilation in patients with ARDS found an increased mortality in the high-volume arm.[9] This low-volume approach remains controversial, and the trial results are debated.[15-18] The strongest criticism of the study is that the low-volume strategy was not compared with standard care (8 mL/kg),[15] but instead to much larger volumes. In addition, 2587 patients who were screened and met enrolment criteria were not entered into the ARDSNet trial. At the end of the study, these patients, who had received standard care, had a mortality rate comparable to the low-volume group (31.7% v 31%).[19] Thus, the ARDSNet trial is criticised for the difference in groups being due to an excessive mortality in the high-volume ventilation arm rather than any beneficial effects of low-volume ventilation.[15] Many authorities maintain that plateau pressure rather than volume should be limited,[20] and there may actually be a benefit with higher tidal volume if pressures are kept low.[19-22]

Interestingly, two recent studies found an association between delivery of larger tidal volume and development of ALI in patients without ALI on presentation.[1,2] Both studies demonstrated an association between routine ventilation using volumes of at least 6 mL/kg predicted BW and the development of ALI. Our audit was to assess the ventilation volumes being administered to mechanically ventilated critically ill patients in a single Australian ICU.

We estimated height using a surrogate marker — arm demispan — and from this calculated predicted BW. It may be argued that the use of surrogate markers of height may not be representative in some groups;[23] that there is considerable variability between the different surrogate markers and actual height in some groups;[24] and that, while there are various surrogate markers of height, none are proven to be superior in the critically ill. In addition to calculating predicted BW, the ARDSNet trial used actual height, rather than a surrogate marker. However, we believe that the surrogate marker, arm demispan, may actually be more appropriate for the ICU population. Arm length is less affected by ageing than height,[25] is more easily measured in bed-bound patients, and has less interobserver variability. It can be assessed in the semi-recumbent position, unlike height which requires the patient to be supine, with the attendant risk of aspiration.[26-28] Further, surrogate markers of height such as demispan have an accepted role in calculating ideal body weight for nutrition assessment.[29] Thus, we considered arm demispan a more precise measurement in older bed-bound patients and, as an accepted technique that can be performed in the semi-recumbent position, it was adopted as the measurement of choice.

We calculated predicted BW using estimated height. Predicted BW was less than recorded BW in mechanically ventilated patients, which was consistent with the finding of a previous retrospective review.[3] It followed that ventilation volumes were greater when using predicted BW than when using recorded weight. While we excluded patients with ARDS from our study, a recently published systematic review recommended ventilating patients with ARDS at volumes less than 7.7 mL/kg.[30] Regardless of an individual clinician's belief in low-volume ventilation, it seems prudent to accurately measure the volume set during ventilation in patients both with and without ALI. Our audit revealed that we had been overestimating the weight of patients, especially women, and thus had been delivering greater than expected tidal volumes.

The recent findings of Gajic et al[1,2] about the benefits of low-volume ventilation in mechanical ventilation are of interest. This theory is controversial, has not been accepted into standard practice, and cannot currently be recommended. While we do not advocate a "cookbook" approach to medicine, measurement of predicted BW may provide further information to the clinician and avoid inadvertent delivery of larger than expected tidal volumes. Two groups — women and the obese — may be particularly at risk of overestimation of body weight.

Studies have suggested women are at greater risk of complications during mechanical ventilation.[1,31-33] However, this association has not been demonstrated in all studies.[34] Our finding that larger volumes were delivered to women suggest that this may be the mechanism to explain the differences in outcomes that have been seen between the sexes in some of the studies.

The prevalence of obesity is increasing, and currently 19% of Australian males and 22% of females are obese.[35]

Our audit did not address obese patients as a defined subgroup, but obesity is a risk factor for poor outcome in mechanical ventilation, with studies demonstrating an association with increased mortality[36,37] or morbidity.[38] As previously discussed, a retrospective review found obese patients received higher tidal volumes than patients with normal BMI, and that, when obese patients were ventilated on a predicted BW protocol, there was no association between body weight and mortality.[3] Given that predicted BW was less than recorded BW, it is conceivable that overestimation of weight could be especially problematic for obese patients, leading to ventilation with inappropriately large tidal volumes.

Using evidence-based medicine criteria, such as those in the *JAMA* users' guide,[39] it appears the association between high-volume ventilation (in non-ALI) and poor outcome in Gajic et al's studies cannot be generalised to Australasian ICUs. In the second of their studies on low-volume ventilation in non-ALI patients, 6% of patients developed ARDS,[2] and 24% developed ALI.[1] This lung abnormality developed in patients who did not meet the criteria for either diagnosis on admission. This very high incidence does not reflect current practice in this country, as the incidence of ARDS in Australian ICUs is 5.5% per ventilated patient, and only 2.1% among those who did not meet the criteria for ARDS on Day 1.[40] In our ICU, 2.34 per 100 ventilated patients met the criteria for ARDS in 2006 (unpublished data). The reason for such a high incidence of lung injury in the overseas study remains unclear.

Limitations of our study include the small sample size. However, given that it focused on the relationship between predicted BW and recorded BW (rather than patient outcomes), a small sample size was sufficient. Many of our inferences regarding the impact of predicted BW make use of evidence obtained from the two larger studies of Gajic et al, which focused on outcomes. Gajic has suggested that low-volume ventilation protects against development of ALI in mechanically ventilated patients. Our study highlights that use of non-volume controlled ventilation in mandatory mode may lead to the delivery of greater than expected tidal volumes. We also found that arm demispan is quick and easy to measure, with no cost and no side effects. Although more studies are needed, the calculation of predicted BW as part of routine clinical assessment may provide additional useful information to guide ventilation.

Conclusions

Predicted BW was less than recorded BW. As a consequence, larger tidal volumes were delivered, when calculated as mL/kg from predicted BW rather than actual BW. In addition, women received higher volumes than men when using predicted BW, suggesting that they may be particularly at risk of receiving excessive tidal volumes. Calculation of predicted BW using demispan as a surrogate marker of height is a cheap, easy and non-invasive tool for clinical assessment that may be of benefit in the ventilation of critically ill patients.

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