Lung protective mechanical ventilation
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Chapter 4

Feedback and Education Improve Physician Compliance in Use of Lung-Protective Mechanical Ventilation

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Abstract

**Background:** Use of lung-protective mechanical ventilation (MV), by applying lower tidal volumes, is recommended in patients suffering from acute lung injury (ALI) or acute respiratory distress syndrome (ARDS). Recent data suggest that lung-protective MV may benefit non-ALI/ARDS patients as well. The aim of this study was to analyze tidal volume settings in 3 intensive care units (ICUs) in the Netherlands, and to determine the effect of feedback and education concerning use of lung-protective MV.

**Design:** Observational study.

**Setting:** One academic - and two non-academic “closed format” intensive care units.

**Patients:** Intubated mechanically ventilated subjects.

**Interventions:** Feedback and education, concerning lung-protective MV, with special attention to the importance of closely adjusting tidal volumes to predicted body weight (PBW).

**Results:** Before intervention, tidal volumes for all ICU-patients were 9.8 ± 2.0 ml/kg PBW (mean ± SD for all 3 hospitals). No differences were seen between patients suffering from ALI/ARDS and those not meeting the international definition criteria for ALI/ARDS. Six months after intervention, tidal volumes dropped to 8.1 ± 1.7 ml/kg PBW (p < 0.05 versus before education), and the percentage of undesirable ventilation data points, defined as tidal volumes > 8 ml/kg PBW, declined significantly (84% versus 48%, p < 0.05). Only 4 patients received tidal volumes < 6 ml/kg PBW. Lower tidal volumes were still used after 12 months. Tidal volumes in patients on mandatory mechanical ventilation and patients breathing on spontaneous modes were similar.

**Conclusion:** Feedback and education improve physician compliance in use of lung-protective MV.


Introduction

Mechanical ventilation (MV) is routinely applied in critically ill patients. Although frequently life-saving MV may induce injury to the lungs, known as “ventilator-induced lung injury” (VILI). Alveolar overdistension and repetitive opening and closing of atelectatic lung units are thought to play a causative role of VILI in patients with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS) [1]. This hypothesis brought investigators to use lung-protective MV strategies in patients with ALI/ARDS, either by applying lower tidal volumes [2] and/or sufficient levels of positive end expiratory pressure (PEEP) [3]. The ARDS Network trial confirmed that MV with lower tidal volumes resulted in a significant decrease in mortality and increased the number of ventilator-free days. Recently published data, presented earlier in preliminary format, also suggested that non-ALI/ARDS patients may benefit from lower tidal volumes [4].

Many medical advances are only slowly brought into practice. Although clinicians in teaching hospitals are often early supporters of new medical advances, several reports show reluctant use of lung-protective MV [5-7]. One reason for not using lower tidal volumes in ALI/ARDS patients is poor physician recognition of patients with ALI/ARDS [8,9]. Other barriers for the use of lung-protective MV include concerns over patient discomfort and tachypnea and concerns over hypercapnia, acidosis and hypoxemia [8]. In addition, the importance of using predicted body weight instead of actual body weight may have been neglected [10].

The aim of this observational study, was to analyze tidal volume settings in mechanically ventilated patients in 3 “closed format” intensive care units in the Netherlands. To determine the effect of feedback and education concerning use of lung-protective MV, we studied tidal volume settings after 6 months in the same centres. In addition, to determine the long term effect of our intervention, we studied tidal volumes in an additional set of patients one year later in one centre.

Methods

Study centres

We studied MV-settings in one academic ICU (Academic Medical Center (AMC), Amsterdam, the Netherlands) and two non-academic ICUs (Gelre Hospital (GH), location Lukas, Apeldoorn, the Netherlands and Medical Center Leeuwarden (MCL), Leeuwarden, the Netherlands). In the academic centre, a large teaching hospital, the ICU is a 28-bed “closed format” department, in which medical/surgical patients (including cardiothoracic and neurosurgical patients) are under the direct care of the ICU-team. As part of the team, nurses can make ventilator therapy recommendations, but unit policy mandates that all changes in MV-settings are ordered by physicians. The ICU-team comprises 8 full-time
intensivists, 8 subspecialty fellows, 12 residents and occasionally 1 intern. In the GH, an affiliated teaching hospital, the ICU is a 10-bed “closed format” department. In this hospital, nurses can make ventilator therapy recommendations and changes. In this ICU, in contrast to the ICU in the academic centre, at night physicians are only present on request. The ICU-team consists of 2 full-time intensivists, 5 part-time intensivists who participate in duty shifts, and 1 resident. The MCL, a large general teaching hospital in the north of the Netherlands, has a 13-bed “closed format” mixed ICU. In this centre, nurses can make ventilator therapy recommendations, although unit policy mandates that changes in MV-settings are ordered by physicians. The ICU-team comprises 6 full-time intensivists, 2 residents, and occasionally interns.

**MV-protocol**

In the academic centre, a written MV-protocol is available for all ICU-members, both on the intranet, and in printed form. In short, this protocol advises pressure-controlled (PC)-MV or pressure support (PS)-MV in all patients. Levels of positive end expiratory pressure (PEEP) are adjusted to PaO₂-levels. Use of prone positioning is recommended in patients requiring injurious FiO₂-levels (> 0.6). There is a clear recommendation on tidal volume settings, stating that tidal volumes have to be between 6 and 8 ml/kg predicted body weight (PBW) in all patients, irrespective of the presence of ALI/ARDS (the upper limit of 8 ml/kg PBW was chosen based on the ARDS Network protocol [2], in which tidal volumes were allowed the be as high as 8 ml/kg PBW in some circumstances). In the protocol it is stated that “mild hypercapnia” is accepted in patients with ALI/ARDS (but no limits for PaCO₂ are given). In case of PS-MV, the level of support is set to reach a respiratory rate between 10 and 20 breaths/minute, or a level at which the patient is comfortable breathing, according to patient and/or physician vision. However, use of lower tidal volumes takes precedence over respiratory rate, allowing higher respiratory rates. No written MV-protocol is available in the other two hospitals.

**Patients and data-collection**

The study included 114 consecutive, intubated MV subjects aged 18 years or over, divided into two groups: 50 before intervention (31 men, 19 women) and 64 after (37 men, 27 women; table 1). In a third data collection period 12 months after intervention 103 patients were examined at the AMC. MV-settings were collected at 3 different time points per day (in proximity to 8 AM, 2 PM and 8 PM) during a period of two weeks (first data collection academic centre: June 2003, GH: October 2003, MCL: November 2003; second data collection academic centre: January 2004, GH: April 2004, MCL: May 2004). These data were recorded by one intensivist in each hospital and one of the authors (EW). Other intensivists/fellows/residents were unaware of the collection of data. Measurements were performed directly before and approximately six months after an educational program. In
the academic centre, during a third period (September 2004) data were collected on tidal volume settings to determine long term effects of the intervention.

Table 1 Patient characteristics in the academic ICU and two non-academic ICU’s, before and after education

<table>
<thead>
<tr>
<th></th>
<th>Academic (AMC)</th>
<th>Non-academic (GH and MCL)</th>
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<tbody>
<tr>
<td></td>
<td>Before (n = 30)</td>
<td>After (n = 45)</td>
</tr>
<tr>
<td>Gender; M/F</td>
<td>18/12</td>
<td>27/13</td>
</tr>
<tr>
<td>Age, years; mean (SD)</td>
<td>55 (21)</td>
<td>62 (15.1)</td>
</tr>
<tr>
<td>ALI/ARDS (%)</td>
<td>43</td>
<td>27</td>
</tr>
<tr>
<td>APACHE II; mean (SD)</td>
<td>21.4 (8.9)</td>
<td>20.1 (7.4)</td>
</tr>
<tr>
<td>SAPS II; mean (SD)</td>
<td>44.1 (17.5)</td>
<td>44.4 (16.4)</td>
</tr>
<tr>
<td>Height, cm; mean (SD)</td>
<td>168 (12.4)</td>
<td>173 (8.2)</td>
</tr>
<tr>
<td>Actual BW (kg); mean (SD)</td>
<td>77.7 (14.3)</td>
<td>77.0 (17.9)</td>
</tr>
<tr>
<td>Predicted BW (kg); mean (SD)</td>
<td>62.1 (12.7)</td>
<td>66.8 (9.0)</td>
</tr>
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</table>

AMC, Academic Medical Center; GH, Gelre Hospital; MCL, Medical Center Leeuwarden; APACHE II: Acute Physiology And Chronic Health Evaluation II; SAPS II: Simplified Acute Physiology Score II; PaO2/FiO2, ratio of partial pressure of arterial oxygen to the fraction of inspired oxygen; IQR, interquartile range; BW, body weight. *p-value < 0.05.

The following MV-data were recorded: MV-mode, FiO2, applied VT, PEEP-level, maximum airway pressure (P-max) in PC-MV or plateau pressure (P-plateau) in volume controlled ventilation, respiratory rate (breaths/min). Tidal volumes were not corrected for ventilator tubes or ventilator-types and only exhaled volumes were recorded. Patient’s length was measured and patient’s weight was collected from the medical record. In case there was no weight recorded, the weight used by the nursing team was taken as actual bodyweight. Arterial blood gases were recorded, the sample closest to the observation was taken for each set. ALI/ARDS (at any time during the MV-episode) was diagnosed by one intensivist in every hospital and one of the authors (EW), using consensus criteria for ALI/ARDS: acute onset of respiratory failure, a PaO2/FiO2 ratio of ≤ 300 mmHg, bilateral infiltrates on the chest radiograph [11].

Definitions

Actual body weight was defined as the body weight of patients measured before admission to the hospital or ICU. Predicted body weight (PBW) was calculated by the following formula: for male patients PBW (kg) 50 + 0.91 (centimetres of height – 152.4), for female patients PBW (kg) is 45.5 + 0.91 (centimetres of height – 152.4) [12]. Applied tidal volume was defined as expiratory volume measured by the ventilator. The tidal volume, expressed as ml/kg PBW, was calculated by dividing applied tidal volume by PBW for each patient.

Feedback and education

In the academic centre, the intervention consisted of: (1) a presentation of the results of the first data collection to all ICU-physicians (“feedback” on current practice); (2) a discussion on studies using lower tidal volumes and on potential reasons for not using
lower tidal volumes, including the importance of use of PBW -instead of actual bodyweight- to set tidal volumes ("education"); (3) a demonstration of the results of the first data collection to all ICU-nurses. In the GH, a similar intervention took place, and a MV-protocol was introduced saying that tidal volumes should be between 6 and 8 ml/kg PBW. In the MCL, only feedback to the physicians of the first data collection took place, and the importance of using PBW to set tidal volumes was emphasized, but no written protocol was introduced.

Statistical analysis
After we checked that day 1 MV-settings were not different from average data for all respiratory variables we choose to use the mean of all respiratory variables per patient in the subsequent tables, figures and statistical analyses. Statistical analysis was performed using for continuous data the Kruskal-Wallis test and post-hoc analysis with a Mann-Whitney U test; for categorical data the Chi-square test was used. All data are presented in the figures for all patients, and as means (SD) or as median (interquartile range) in the text or table. A p-value < 0.05 was considered significant.

Results
Tidal volumes
Before intervention, tidal volumes of patients without ALI/ARDS were 9.7 ± 1.9 ml/kg PBW. After intervention, tidal volumes declined significantly to 8.0 ± 1.7 ml/kg PBW (p < 0.001) (figure 1). The percentage of non-ALI/ARDS patients with tidal volumes > 8 ml/kg PBW declined from 88% before to 49% after intervention in the academic centre (p = 0.007) and from 78% to 40% in the non-academic centres (p = 0.011). The percentage of patients with tidal volumes > 10 ml/kg PBW declined from 41% before to only 9% after intervention in the academic centre (p = 0.008), and from 33% to 10% in the non-academic centres (p = 0.023).

For ALI/ARDS patients tidal volumes dropped from 9.9 ± 2.2 ml/kg PBW to 8.2 ± 1.8 ml/kg PBW (p = 0.013) (figure 2). The number of observations in which tidal volumes were > 8 ml/kg decreased from 85% to 42% in the academic centre (p = 0.03), and from 82% to 67% in the non-academic centres (p = 0.45). The percentage of patients with tidal volumes > 10 ml/kg PBW declined from 39% before to 8% after intervention in the academic centre (p = 0.08), and from 73% to 22% in the non-academic centres (p = 0.028).
Figure 1. Tidal volumes declined in non-ALI/ARDS patients after intervention. Tidal volumes measured before (closed symbols) and after intervention on the use of lung-protective mechanical ventilation (open symbols) in one academic and two non-academic centres. Each dot represents the mean tidal volume of an individual patient: tidal volumes were collected three times per day during a period of two weeks. Horizontal lines represent median tidal volumes. The area between the dotted lines indicates target tidal volume (as described in the mechanical ventilation protocol). p-value indicates statistical significance between mechanically ventilated patients before and after intervention.

Tidal volume based on PBW versus tidal volume based on actual body weight (before intervention)

The mean PBW (63.6 ± 10.6 kg) was 15% less than the mean actual body weight (76.4 ± 14.2 kg). When tidal volumes were adjusted to actual body weight instead of predicted body weight, tidal volumes were > 8 ml/kg in 43% and 81%, and > 10 ml/kg in 17% and 38% in the academic centre and non-academic centres, respectively.

Ventilator modes, PEEP and P-max

Pressure controlled (PC) or pressure support (PS) MV-modes were most often used in all centres. However, Adaptive Support Ventilation (as provided by Hamilton Galileo) was used in a significant number of patients in the MCL. Levels of PEEP, P-max, respiratory rate and ventilator mode are demonstrated in table 2. Before education, in 19% of the observations of all ICU-patients P-max was > 30 cmH₂O, with no difference between ALI/ARDS and non-ALI/ARDS patients. After intervention P-max was > 30 cmH₂O in 8% of all observations (p = 0.1).
Figure 2: Tidal volumes declined in ALI/ARDS-patients after intervention. Each dot represents the mean tidal volume of an individual patient: tidal volumes were collected three times per day during a period of two weeks. Horizontal lines represent median tidal volumes.

Table 2: Mechanical ventilation data in the academic ICU and two non-academic ICUs, before and after education.

<table>
<thead>
<tr>
<th>Ventilator mode</th>
<th>Academic (AMC)</th>
<th>Non-academic (GH and MCL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before (n = 30)</td>
<td>After (n = 45)</td>
</tr>
<tr>
<td>ASV</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>VCV</td>
<td>2.2%</td>
<td>6.6%</td>
</tr>
<tr>
<td>PSV</td>
<td>60.4%</td>
<td>65.9%</td>
</tr>
<tr>
<td>PCV</td>
<td>37.4%</td>
<td>27.5%</td>
</tr>
<tr>
<td>PEEP; cm H₂O</td>
<td>6.3 [5.0-9.2]</td>
<td>7.5 [6-12.9]*</td>
</tr>
<tr>
<td>P-max or P-plat; cm H₂O</td>
<td>20.5 [15.8-25]</td>
<td>21 [17.8-23.3]</td>
</tr>
</tbody>
</table>

Blood gas analysis:

| PaCO₂ (mmHg)   | 36.3 [34.0-40.0] | 39.4 [34.7-43]          | 38 [33.4-45]     | 37.2 [33.6-43.3] |

* values are given as median [interquartile range]; AMC, Academic Medical Center; GH, Gelre Hospital; MCL, Medical Center Leeuwarden; ASV, adaptive support ventilation; VCV, volume controlled ventilation; PSV, pressure support ventilation; PCV, pressure controlled ventilation. * p-value < 0.05.
**pH and PaCO₂-levels**

Before intervention, no differences in pH and PaCO₂-levels were seen between ALI/ARDS patients and non-ALI/ARDS patients. Hypercapnia (defined as PaCO₂ ≥ 50 mmHg) occurred in only 2% of all patients. After intervention, hypercapnia occurred in 13% of all patients (p = 0.04), with no difference between ALI/ARDS patients and non-ALI/ARDS patients.

**Relation between mode of ventilation and tidal volume**

To determine whether tidal volumes were larger with different modes of MV in the ICU, we divided patients who were mechanically ventilated with pressure support (PS) from those who were ventilated with pressure control (PC). No differences in tidal volumes were seen between the two groups, both before and after intervention (**figure 3**).

![Figure 3](image)

**Figure 3** Tidal volumes during spontaneous mechanical ventilation (pressure support, PS) or mandatory mechanical ventilation (pressure control, PC) were similar after intervention. Tidal volumes in patients, either on PS or PC mechanical ventilation. Each dot represents the mean tidal volume of an individual patient. The horizontal line represents median tidal volume per group. NS, not significant.

**Long term results**

In the academic centre, 1 year after intervention, tidal volumes were 7.8 ± 1.3 ml/kg PBW compared to 8.1 ± 1.7 ml/kg PBW six months before (p = 0.27). These tidal volumes, six
and twelve months after intervention, were significantly lower than before intervention (p < 0.001). Tidal volumes in ALI/ARDS-patients and those without lung injury were 7.5 ± 1.1 ml/kg PBW and 7.9 ± 1.3 ml/kg PBW, respectively (figure 4).

**Figure 4** Long term results. Tidal volumes twelve months after intervention in the academic centre. Open symbols represent non-ALI/ARDS patients and closed symbols ALI/ARDS patients. Each dot represents the mean tidal volume of an individual patient. Horizontal lines represent median tidal volumes per patient group.

**Discussion**

One valuable advance in the field of MV has been the clear demonstration that use of lower tidal volumes, as compared to conventional MV using higher tidal volumes, resulted in a significant reduction of mortality in patients with ALI/ARDS [2]. Other so-called lung-protective MV-approaches, such as use of pressure controlled MV, optimal PEEP, recruitment manoeuvres, prone positioning, high frequency oscillation and permissive hypercapnia, have not been proven to be effective. Although guidelines support the use of lower tidal volumes in ALI/ARDS-patients [13], physicians have been slow to adopt lung-protective MV using lower tidal volumes. In the present study, we show that an educational program consisting of showing actual daily practice to all ICU-team members,
emphasizing the use of PBW instead of actual body weight to set tidal volumes, can reduce tidal volumes significantly.

The results of our study are in line with those from other investigators. Several published and unpublished studies have shown the reluctance of physicians and respiratory therapists in applying lung-protective MV using lower tidal volumes [6,7,14]. Reported reasons for not using lower tidal volumes are diagnostic uncertainty [9], and unwillingness to use lower tidal volumes [8]. Importantly, many ICU-physicians think normal tidal volumes are larger than they are [15]. In addition, use of actual body weight instead of PBW to calculate tidal volumes may result in tidal volumes becoming too large [10]. Our results may underscore the use of predicted body weight instead of actual bodyweight to calculate tidal volumes. Indeed, there was a large difference between actual bodyweight and predicted body weight in our data set. When applied tidal volumes would have been expressed as ml/kg actual bodyweight, tidal volumes were significantly lower. Others have reported on diverse strategies to influence MV-practices [16,17]. Roche and co-workers successfully used an intensive educational program, encouraging an active role for ICU-nurses, and simple protocols written to support increased involvement of nursing staff in the set-up and adjustment of mechanical ventilators [17]. It must be mentioned, however, that in this study it was not stated whether tidal volumes were adjusted to PBW (i.e., when actual body weight was used for calculation of tidal volumes, these volumes may still have been too high).

Providing feedback on previous practice has been shown to be more effective than simple education [18]. Recently, Cook and co-workers emphasized the importance of an environmental scan (to establish the extent to which a proven strategy is not being used) and understanding of current behaviour (to determine why a strategy is not used) to improve daily practice [19]. We performed an environmental scan by analyzing current MV-settings in our ICU’s (showing underutilization of lung-protective MV, using lower tidal volumes), and tried to understand why this happened (discussion on potential reasons for not using lower tidal volumes, illuminating that actual body weight in stead of PBW was used to calculate tidal volumes). We then, successfully, targeted behaviour by emphasizing the significance of use of lower tidal volumes, as well as the importance of using PBW to set the ventilator. Using this approach, within 6 months tidal volumes declined significantly. Importantly, after 12 months lower tidal volumes were still used.

Although tidal volumes declined after intervention, in a number of observations tidal volumes were still > 8 ml/kg PBW. In addition, after intervention there was still residual variation. Several reasons may apply for these findings. First, from our experience, a number of patients have tidal volumes > 8 ml/kg PBW with the lowest level of pressure support (i.e., < 5 cm H₂O). Second, there may have been reasons for applying larger tidal volumes (like severe acidosis). A wide variation in tidal volumes has also been noted by
others [4,7]. Unwanted variation remains common in clinical care unless the results of scientific trials and in our study it may also have been caused by unwillingness of the ICU-team members to strictly apply to the MV-protocol. However, our current analysis does not provide sufficient data to prove this. Nevertheless, we do think that improving MV-settings is a continuous process: new (probably similar) interventions are needed to persuade a further decline in tidal volumes.

It might seem surprising that we advocate the use of lower tidal volumes in all mechanically ventilated patients, irrespective of the presence of ALI/ARDS. A recent study, however, shows that patients admitted for other reasons than ALI/ARDS, ventilated with higher tidal volumes have an increased incidence of late-onset ALI/ARDS [4]. In addition, animal studies have shown that lung-overdistension induces lung injury [20]. Indeed, MV with relatively high tidal volumes can induce ventilator induced lung injury (VILI) in animals with healthy lungs [21,22]. Although additional studies must be performed to show whether lower tidal volumes truly benefits patients without ALI/ARDS, at present we use lower tidal volumes in these patients too.

The only two clinical trials showing mortality benefit from lung protective ventilation in ALI targeted either tidal volumes less than 6 ml/kg PBW [2], with the allowance of using tidal volumes < 8 ml/kg PBW in some circumstances, or tidal volumes less than 6 ml/kg actual body weight [3]. However, our protocol prescribed tidal volumes between 6 and 8 ml/kg PBW, and therefore, at least in patients with ALI/ARDS, our intervention may not be sufficient to improve lung-protective MV.

From the present study it can not be concluded which part of the intervention had the greatest impact. Although we consider feedback on current practice and discussions on new insights on MV and potential barriers to introduce results from trials of importance, it might be that just a discussion on MV may have caused a change in practice. Further one has to keep in mind that any change observed might have been due to other factors than the intervention. It can be suggested that, perhaps, enough time had passed with further debate in the literature and locally that tidal volumes would have been reduced anyway.

In conclusion, after feedback and education, ICU-physicians prescribed lower tidal volumes more frequently. Our results may underscore the use of predicted body weight instead of actual bodyweight to calculate tidal volumes.
References
