Protective lung ventilation in Acute Respiratory Distress Syndrome: What is new?

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Abstract

Acute respiratory distress syndrome (ARDS) is associated with high mortality and morbidity. Traditional ventilation with large tidal volumes aimed at normalisation of blood gases is usually associated with significant injury to the lungs. Protective lung ventilation (PLV) with smaller tidal volumes, higher levels of positive end-expiratory pressure (PEEP) and control of plateau pressures is the accepted mode of ventilation in patients with ARDS. Recruitment manoeuvres have been part of the protocol in PLV. However, considerable controversy surrounds the optimal PEEP that may be applied to these patients. Similarly, there is no consensus on the usefulness of recruitment manoeuvres in these sick patients. This review tries to find some answers to the best way to use PLV, PEEP and recruitment manoeuvres in patients with ARDS.

Keywords: Acute respiratory distress syndrome, protective lung ventilation, positive end-expiratory pressure, recruitment manoeuvre.

Introduction

Mortality in patients with acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) approaches 40-60 percent.[1] Mechanical ventilation is critical in patients with ARDS to maintain adequate gas exchange and reduce the work of breathing. Traditional ventilation uses 10-15 mL/kg of tidal volume (V_T) which is much more than in normal patients at rest (7-8 mL/kg). However, this is frequently necessary to maintain normal values of pH and partial pressure of carbon dioxide in blood ($PaCO_2$). Ventilation with large tidal volumes can cause disruption of pulmonary epithelium and endothelium, produce intense hypoxaemia, atelectasis and release of inflammatory mediators. This review will specifically look at protective lung ventilation (PLV) and try to answer some of the controversies surrounding this strategy. However, rescue methods such as airway pressure release ventilation (APRV), prone ventilation or high frequency oscillatory ventilation will not be discussed.

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Ventilator induced lung injury

The parenchymal lung injury associated with ARDS is heterogeneous in nature. Using computed tomography of the chest, Gattinoni has described 3 general regions of the lung: a region of normal lung tissue, primarily in the nondependent areas; a region of densely consolidated, fluid filled or atelectatic tissue, primarily in the dependent regions; and a region that is collapsed during expiration but recruitable during inspiration.[2]

Lung injury associated with ARDS can be compounded by mechanical ventilation. Ventilation with high airway pressures can result in *barotrauma*. Incidence of barotrauma is high with plateau pressures (P_{plat}) > 35 cm H_2O than when the P_{plat} are maintained < 30 cm H_2O.[1] The healthy region of

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the lung which receives most of the tidal ventilation tends to get over-distended. This does not manifest as air leak but rather as a diffuse alveolar damage called *volutrauma*. Volutrauma usually occurs in the nondependent areas of the lung with normal alveolar units and normal airway resistance. Injury can also occur when lung units are allowed to repeatedly open and close with tidal ventilation *(atelectrauma)*. Both atelectrauma and volutrauma can trigger release of inflammatory mediators *(biotrauma)* and induce bacterial translocation which may incite multi-organ dysfunction syndrome (MODS) and increase morbidity and mortality.[3,4]

These patients need high inspired concentrations of oxygen (FiO_2) which can also be toxic in humans. The toxic threshold for inducing damage is debatable. It is generally desirable to reduce the FiO_2 to < 60 percent. Inspired oxygen concentrations < 40 percent can be tolerated for prolonged periods without lung injury.

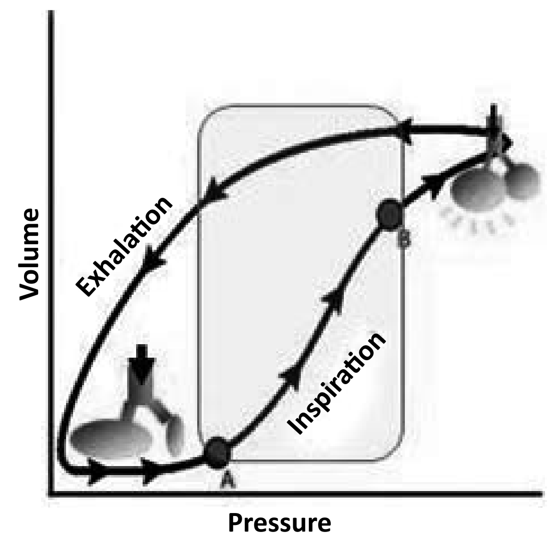

Figure 1: Shows a pressure volume loop from a patient with ARDS. Point A shows the lower inflection point ($P_{flex.i}$). Point B represents the upper inflection point on the inspiratory limb. The bracketed area represents the 'safe zone' of ventilation in ARDS. As can be observed from the figure, allowing the PEEP to fall below point A would result in collapse of alveoli while ventilating above point B would result in over-distention of alveoli.

Concept of protective lung ventilation (PLV)

The concept of lung protective ventilation strategy is aimed at opening up as many alveolar units as possible and maintaining the patency of the airways during the course of the respiratory cycle while ensuring adequate oxygenation, carbon dioxide removal and acceptable blood pH. *Figure 1* shows the pressure volume relationship of a patient with ARDS.

Initial application of pressure to the patient's airway does not result in an increase in the lung volume as most alveolar units remain collapsed. Once a critical pressure is achieved in the airway, a sudden increase in lung volume is noticed (critical opening pressure or lower inflection point ($P_{Flex.i}$)). With increasing pressures, the slope of pressure-volume (P-V) curve rises sharply, signifying improved compliance and easier inflation. When the lung is near total inflation, the curve once again becomes flatter indicating that further increase in airway pressure is unlikely to recruit more alveolar units (upper inflection point). It is also important to note that for any given pressure, a larger lung volume exists during the deflation part of the curve than during inflation. This volume difference (hysteresis) is to a large extent dependent on the surfactant function, the degree of lung impairment and recruitability of lung units. Less hysteresis is seen with normal function or less recruitable alveolar units. The primary principles behind protective lung ventilation are, therefore, to:

a) Avoid repetitive opening and closure of the alveolar units by application of adequate positive end expiratory pressure (PEEP) to maintain patency of lung units throughout the respiratory cycle.
b) Ventilate patients using airway pressures that limit the fluctuations in pressure between the set PEEP and the upper inflection point to prevent overdistension of alveoli. Ideally ventilation should take place in the "safe zone" of the P-V loop *(Figure 1)*. The upper limit of airway pressure in PLV is generally accepted as < 30 cm H_2O.

Oxygenation target of PLV

Oxygenation targets include a PaO_2 55 - 80 mm Hg or systemic arterial oxygen saturation (SaO_2) of 88 – 92 percent.

Ventilatory strategies during PLV

The ARDS Network study, which to date is the only ventilator related study showing an outcome benefit, is the benchmark for management of patients with ARDS.[5] There are three important criteria to be followed in this strategy of ventilation.

a) V_T should be maintained at < 6 mL/kg of predicted body weight irrespective of the mode of ventilation.
b) Maintain the P_{plat} < 30 cm H_2O irrespective of the mode of ventilation or PEEP levels.
c) Use of 'adequate PEEP' to ensure that alveoli do not collapse at end-expiration.

The combined end points of 6 mL/kg V_T and a P_{plat} < 30 cm H_2O can result in unacceptably low blood pH due to elevated $PaCO_2$. To overcome this, the respiratory rate may be increased to a maximum of 35 breaths/minute. Increasing respiratory rates beyond this point can result in generation of auto-PEEP and may be counterproductive. A low pH may be due to high $PaCO_2$ as well as metabolic acidosis which is not uncommon in patients with multi-organ dysfunction. Buffering agents may have to be used if the blood pH falls below 7.15.

If the P_{plat} rises > 30 cm H_2O with a V_T of 6 mL/kg, further reduction in the V_T (to 4 mL/kg) may be required. *Figure 2* shows a flow chart that may be used to manage patients with the above mentioned primary targets.

Failure of PLV strategy: Breaching the set targets

The P_{plat} threshold of 30 cm H_2O can be exceeded under the following circumstances:[6]

a) If the patient has severe hypoxaemia (PaO_2 < 50 mm Hg or SaO_2< 88%) despite FiO_2 1.0 and has a P_{plat} around 30 cm H_2O even with a V_T of 4 mL/kg to allow for further increases in PEEP to improve oxygenation.
b) If the patient has pH < 7.15 despite buffering, to allow for a larger V_T to reduce CO_2 load.

Management of refractory hypoxaemia

Despite the valiant efforts made to adjust the ventilation of patients with ARDS, a significant number of patients can still remain hypoxaemic. PLV is considered as a failure under the following conditions:

a) Despite FiO_2 1.0, PEEP > 20 cm H_2O with a PLV for > 24 h; the PaO_2 is < 55 mm Hg.
b) PLV > 24 - 72 h with FiO_2 > 0.7 and PEEP > 15 cm H_2O to maintain adequate oxygenation.

Rescue therapy should be initiated in these patients rather than take a *'wait and watch'* approach. In addition to increasing the FiO_2, alternative techniques of ventilation such as airway pressure release ventilation (APRV), inverse ratio ventilation (IRV), prone ventilation and high frequency oscillatory ventilation should be tried in these patients. Each of these ventilation strategies has its own benefits and drawbacks. Inhaled nitric oxide has also been used to counter the hypoxaemia associated with ARDS with variable results.

In addition to increasing FiO_2 in response to refractory hypoxaemia, increasing the mean airway pressure (MAP) may also help. This can be achieved by increasing the duration of inspiration (increasing pause time during VCV or preferably using PCV), increasing PEEP and increasing ventilation pressure. Establishing an optimal PEEP is the first step as this is the most practical approach to management of hypoxaemia.

Pressure control *versus* volume control ventilation

PCV is time cycled and pressure targeted. During inspiration, flow from the ventilator pressurises the circuit and the lungs. As the lungs get inflated, flow from the ventilator progressively reduces. If inspiration is long enough to achieve zero flow from the ventilator, the lungs are maximally inflated for that pressure and the peak airway pressures (P_{peak}) on PCV will be the same as P_{plat}.

PCV is often used as a backup in patients with worsening oxygenation. PCV is initiated when

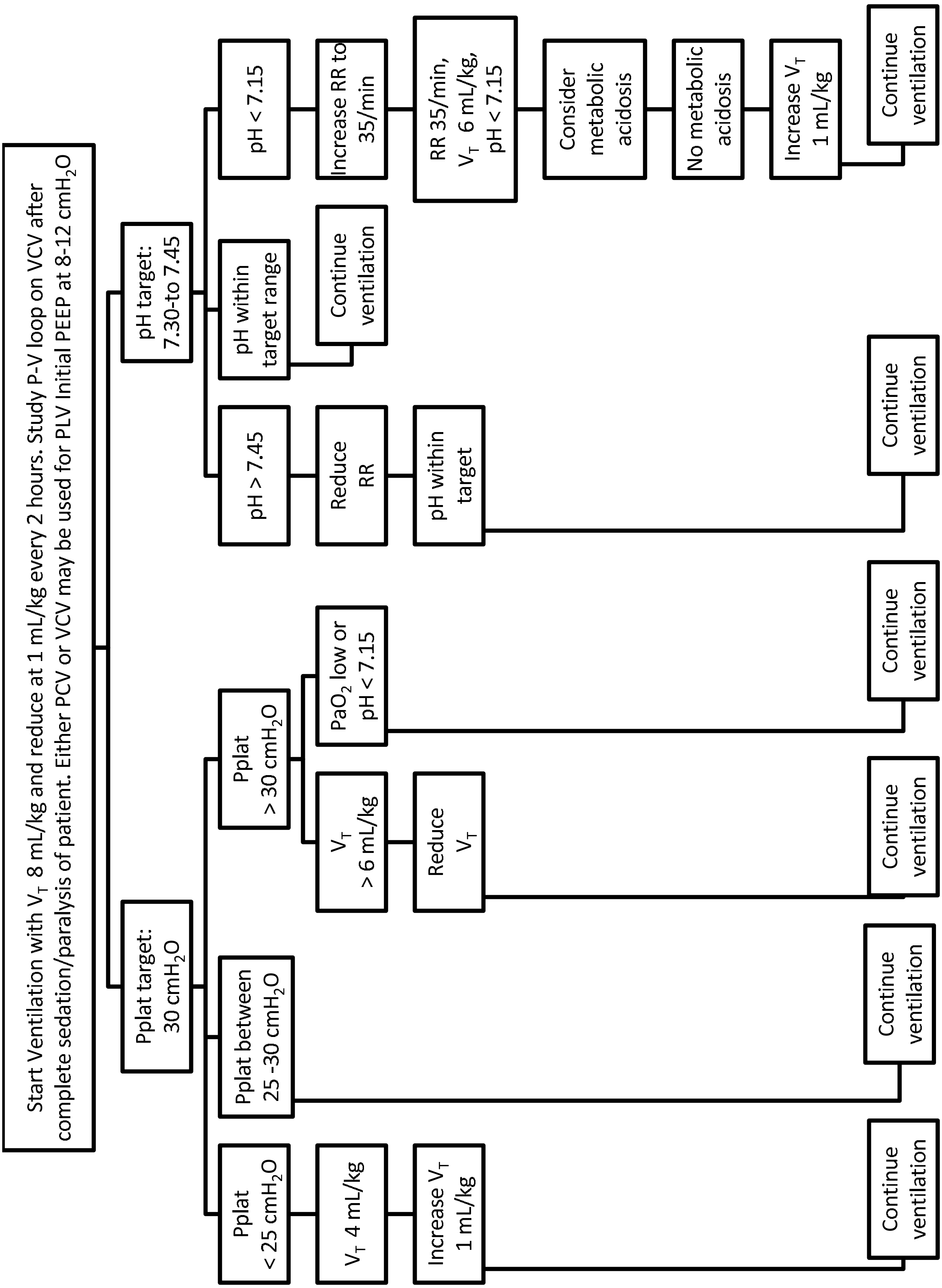

Figure 2: Flow chart of PLV

a) P_{plat} on VCV is above the acceptable P_{plat}
b) When patients are uncomfortable with VCV or when oxygenation is low
c) When prolonged inspiratory time (Ti) is required to increase the mean airway pressure (MAP).

It is important to remember that when P_{plat} is excessive during VCV and patient is switched to PCV, a lower P_{plat} (pressure control level) is only possible at the expense of a lower V_T and probably permissive hypercapnoea. A potential disadvantage of PCV is that as the lung mechanics become worse, the V_T delivered will automatically reduce and in the same token, when lung mechanics improve, the delivered V_T will increase resulting in volutrauma. The variable flow available with PCV may be more acceptable for a patient exhibiting significant respiratory efforts and who are asynchronous with the fixed flows of VCV. This can reduce the work of breathing and the requirement for sedatives and muscle relaxants.

PCV is best suited for improvement in oxygenation. Longer T_i in PCV may result in recruitment of lung units with longer time constants. As the T_i increases, the MAP also progressively increases contributing to improved oxygenation. However, care must be taken to prevent development of autoPEEP. The expiratory flow wave form may be useful in assessment of autoPEEP. The T_i should be prolonged not more than to the point of creating an autoPEEP regardless of the I:E ratio, unless the intent is to create an autoPEEP. A concern with autoPEEP is that it is not uniformly distributed especially in diseased lung such as ARDS. As auto-PEEP is created, the driving pressure and thus, the delivered V_T reduces.. This will protect the lung against increased inspiratory pressures unlike VCV.

Setting an optimal PEEP

Confusion still prevails regarding the ideal PEEP to be used. The initial PEEP is set at 8-12 cm H_2O and then either the low PEEP table or the high PEEP table may be followed. The ARDS Net study used a maximum PEEP of 24 cm H_2O to attain the target oxygenation.[5] The FiO_2 and PEEP adjustments were done based on the PaO_2 attained. In this study, although there was a provision to increase PEEP up to 24 cm H_2O in case target oxygenation was not attained, this level of PEEP was not required in any of the patients. The ALVEOLI study used higher and lower PEEP tables.[7] However, after recruitment of 171 patients the higher PEEP table was re-adjusted to obtain a minimum PEEP of 12 cm H_2O. If the oxygenation target cannot be achieved with the highest level of PEEP suggested (24 cm H_2O) with FiO_2 1.0, then the PEEP could further be increased in steps of 2-5 cm H_2O to a maximum of 34 cm H_2O.[6] If there was no significant improvement in oxygenation within four hours, then the PEEP should be reduced to 24 cm H_2O. This additional management strategy may be required only in a small subgroup of patients with severe forms of H1N1 infections.

Generating a P-V loop and setting an optimal PEEP based on P-V loop

There are two techniques to generate a static P-V loop in ARDS patients. Both techniques require deep sedation or paralysis of the patients. The first technique uses computerised tomography (CT) to construct the pressure volume loop. The patient is initially ventilated with a V_T 10 mL/kg and FiO_2 1.0 to standardise the lung volume history. The patient is then placed on continuous positive airway pressure (CPAP) mode at 0 cm H_2O to allow for complete deflation of the lungs.[8] Subsequently, CPAP is increased at 5 cm H_2O increments till 35 cm H_2O. At each level of CPAP, further increment in CPAP is done only when the flow reaches zero level to ensure static conditions. The patient is then ventilated normally for 5 minutes. To trace the deflation limb of the P-V loop, the patient is again switched to CPAP mode at 0 cm H_2O. The airway pressure is then increased to 35 cm H_2O and reduced at intervals of 5 cm H_2O until zero CPAP. Lung volumes at different CPAP levels are computed from the CT scan pictures to generate a P-V loop that describes various parameters useful for assessment.

A clinically useful P-V loop can also be generated when the inspiratory flow is < 10 L/min. This can be done in clinical practice by ventilating the patients in VCV mode with V_T 10 mL/kg at zero PEEP and reducing the respiratory rate (< 6 breaths/min) so as to ensure a long inspiratory time. This will result in a peak inspiratory flow of < 10 L/min. A P-V curve generated at this low inspiratory flow will show many of the features required for optimal setting of PEEP.

The P-V loop generated through the above measures can be used to set the appropriate PEEP *(Figure 3)*. The inflection point (Pflex.i) and the point of maximum increase in compliance ($P_{mci.i}$) can be identified on the inspiratory limb of the P-V loop. On the expiratory limb, the point of maximum decrease in compliance ($P_{mcd.d}$) and the deflection point ($P_{flex.d}$) can be easily identified. It has been suggested that the PEEP should be set 2 cm H_2O above the $P_{flex.i}$ or the $P_{mci.i}$ on the inspiratory limb of the P-V loop while the maximum inflation pressure should be retained below the upper inflection point (UIP *(Figure 3)*. Because PEEP is an anti-derecruitment manoeuvre (helping to sustain the alveolar units to be open which were recruited / opened during inspiration), the expiratory limb of P-V loop may be more informative. The deflection point on the expiratory limb ($P_{flex.d}$) or the $P_{mcd.d}$ on the expiratory limb of pressure volume curve has been shown to correlate well with improvement in oxygenation, increase in aerated and decrease in nonaerated lung volumes and greater alveolar stability.[8]

Individualised approach: Open lung concept

An individualised approach to setting the PEEP was described by Lachmann in the open lung concept (OLC).[9] The prerequisites in this concept included the use of pressure controlled ventilation, adequate fluid loading and inotropes to ensure that hypotension does not occur during the manoeuvre, use of repeated arterial blood gases as an index of alveolar recruitment and an inspiratory to expiratory ratio (I:E) that ensures end expiratory flows of zero. The OLC attempts to place the patient on the expiratory limb of the P-V curve in steps:

a) An initial arbitrary PEEP set between 15 cm H_2O and P_{peak} at 35 cm H_2O.
b) Then increase PEEP in steps of 2-3 cm H_2O every two min till PEEP reaches 20 cm H_2O (P_{peak} will reach 40 cm H_2O).
c) Increase pressure control levels in steps of 5 cm H_2O every two min (P_{peak} will now be 50 cm H_2O).
d) Gradually reduce pressure control level to identify the pressure level required to deliver a V_T of 6 mL/kg.
e) Gradually reduce the end-expiratory pressure through a decremental PEEP trial (2 cm H_2O every two min) until the critical closing pressure is reached indicating lung derecruitment (identified by a large decrease in tidal volume with a small decrease in pressure level or a large decrease in dynamic compliance).
f) Perform another recruitment manoeuvre to open the lung to total lung capacity (use PCV of 50 cm H_2O).
g) Keep the lung open by setting the PEEP 2 cm H_2O above the PEEP associated with the critical closing pressure.
h) Reduce pressure control level to deliver a V_T of 6 ml/kg.

Evidence for PEEP

Amato and colleagues compared traditional

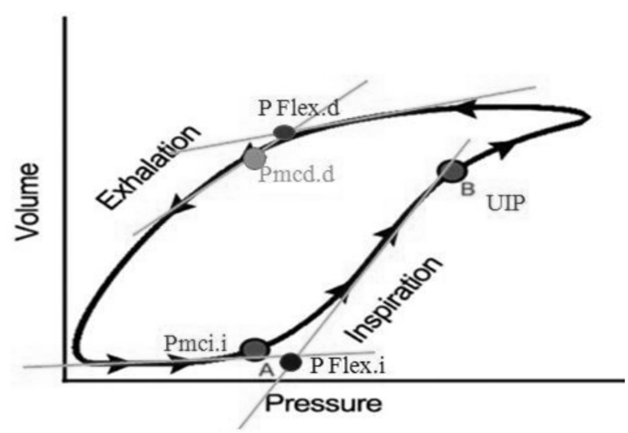

Figure 3: The figure represents the points at which optimal PEEP may be applied. Point A represents $P_{flex.i}$. $P_{mci.i}$ represents the point of maximum compliance increase. Point B represents the upper inflection point. $P_{flex.d}$ represents the point of deflection on the expiratory limb of the curve. $P_{mcd.d}$ represents the point of maximum decrease in compliance on the deflation limb of the curve.

ventilation using large tidal volume, minimum PEEP and normal $PaCO_2$ *versus* PLV using low tidal volume, high PEEP and permissive hypercapnoea in 51 patients with ARDS.[10] PLV resulted in significant reduction in mortality, early weaning from mechanical ventilation and reduction in barotrauma despite use of higher PEEP. Three randomised controlled trials (RCT's) have looked at high PEEP *versus* low PEEP in ARDS patients. The Assessment of Low tidal Volume and increased End-expiratory volume to Obviate Lung Injury (ALVEOLI) study by Bower and colleagues utilised a high PEEP *versus* a low PEEP in 549 patients.[7] The study was truncated because of projected futility of outcome. Although the authors found significant improvement in oxygenation and lung compliance in the high PEEP group, there was no mortality benefit or reduction in ventilator or ICU free days. The Expiratory Pressure (EXPRESS) study which included 768 patients, compared a minimal distension group with a high PEEP group in which the PEEP was adjusted so that the P_{plat} was maintained between 28 - 30 cm H_2O (low V_T in both groups).[11] This study was also terminated at the 18th interim analysis due to futility of outcome. There was no difference in the 28-day or 60-day mortality. However, patients who received high PEEP had more ventilator free days and organ failure free days. The Lung Open Ventilation study (LOVS) differed from the previous study in that the experimental group was allowed higher P_{plat} up to 40 cm H_2O and lung recruitment was used in the high PEEP group.[12] This study involved 983 patients and showed that although there was no outcome benefit with higher PEEP, patients who received higher PEEP had lower incidence of refractory hypoxaemia, death during refractory hypoxaemia and required lesser rescue therapies.

A number of meta-analyses have looked at the benefits of high *versus* low PEEP. The data from the three RCTs mentioned above were pooled together by Briel and colleagues (2299 patients).[13] Although there was no benefit in terms of hospital mortality, the higher PEEP group showed a statistically significant reduction in ICU deaths. Patients in the high PEEP group had less refractory hypoxaemia and fewer patients died during rescue therapy. The study also showed that patients who were already in ARDS ($PaO_2/FiO_2 < 200$) at the time of recruitment into the study had lower mortality and more ventilator free days when they were allocated to the higher PEEP group. Patients who were in ALI ($PaO_2/FiO_2 > 200$) at the time of entry into the study fared worse when they were allocated to the high PEEP group. The study highlighted that high PEEP was more useful in patients with worse disease with recruitable alveoli.

Phoenix *et al* included 2482 patients from six studies in their meta-analysis.[14] They found an early mortality benefit in the high PEEP group. This was attributed to the disproportionate effect of the three smaller studies. A repeat meta-analysis with the 3 larger studies which accounted for 85 percent of the patients showed a trend towards improved mortality with high PEEP although this was not statistically significant. The authors concluded that PEEP may have an independent clinical benefit in very sick patients with ARDS.

Putensen looked at nine studies which included varying combinations of high *versus* low V_T and high PEEP *versus* low PEEP.[15] In addition to their conclusion that low V_T was associated with lower hospital mortality, they also showed that high PEEP had no advantage over low PEEP. However, the number of rescue therapies for life-threatening hypoxaemia and death during rescue therapy was significantly lower in the group receiving high PEEP.

A recent meta-analysis looked at four studies which included the three RCTs mentioned earlier and a study where transpulmonary pressure (PTP) was used for optimisation of PEEP.[16] This study included 2360 patients and showed a nonsignificant trend towards reduced mortality in the high PEEP group.

To determine whether the higher or lower PEEP table should be used in individual patients, Ramnath and colleagues suggest that every patient should be assessed for the presence of recruitable lung units by increasing PEEP from 5-15 cm H_2O and observed for any improvement in compliance and dead space fraction.[17] If the patient responds favourably, one should use the high PEEP table and if there is minimal or no response, the lower PEEP table should be used.

Conclusions regarding optimal PEEP use

From the above discussion, it can be assumed that for patients with ALI, the low PEEP table from the ARDS net study may be most appropriate. In patients with severe ARDS and refractory hypoxaemia, either the high PEEP table, or individualising the PEEP to respiratory mechanics may be beneficial.

Lung recruitment manoeuvres (RM)

Various methods have been used for lung recruitment. The most commonly used method for lung recruitment is with PCV with a constant drive pressure where the PEEP is transiently increased to 35-45 cm H_2O for a period of 30-40 s. Arnal and colleagues showed that most of the recruitment occurs during the first 10 s of the manoeuvre and haemodynamic changes occurred after 30 s of sustained inflation.[18] Marini suggested that stepwise increase in PEEP accompanied by multiple tidal ventilation at each level of PEEP would help stabilise the functional residual capacity at each level of PEEP increment.[19] This technique has been described as the *'staircase recruitment manoeuvre'* by Hodgson and colleagues.[20] Another technique is to maintain a constant, moderate level of PEEP while the pressure control level is progressively increased to a maximum of 45-60 cm H_2O. When the recruitment manoeuvre is completed, the pressure should be sufficient enough to open as many lung units as possible. Some intensivists use an arbitrary upper limit target pressure of 40-45 cm H_2O although it may be as high as 55-60 cm H_2O.

Evidence for RM

Three RCTs have looked at the implications of RM. In 30 patients with ARDS and PLV, the application of RM was associated with significant improvement in PaO_2/FiO_2 ratio and intrapulmonary shunt fraction (Qp/Qt). However, oxygenation indices returned to baseline values within 30 min of the RM.[21] Gattinoni *et al* showed that the amount of recruitable lung varied greatly. Approximately 24 percent of the lung could not be recruited in ARDS patients. In his study, patients with more recruitable lung had lower oxygenation indices, poorer respiratory system compliance, higher dead space ventilation and higher mortality.[22] Brower *et al* evaluated 72 patients after sustained RM at 35-40 cm H_2O for 30 s. Response to RM was variable. The greatest improvement in oxygenation occurred at 10 min after RM and was associated with reduction in systolic blood pressure. There were no significant changes in FiO_2/PEEP required after a RM.[23]

A recent meta-analysis looked at 40 studies that evaluated RMs: 4 were RCT's, 32 were prospective studies and 4 were retrospective cohort studies.[24] The sustained inflation technique (CPAP at 30-40 cm H_2O for 30-40 s) was the most commonly used technique (45 percent), followed by high pressure control (23 percent), incremental PEEP (20 percent) and high V_T (10 percent). Oxygenation was significantly increased after a RM. However, many studies reported a rapid decline in saturation within the next 15-30 min. Adverse events included hypotension and desaturation which were transient and did not interfere with the RM. Significant adverse events including arrhythmias and barotrauma were rare. Sustained inflation with CPAP resulted in greater improvement in oxygenation index as compared to other techniques of RM. The authors concluded that given the uncertain benefits of transient oxygenation improvement, routine use of RM can neither be recommended nor discouraged. RM should be considered on an individual basis in patients with severe lung injury with life-threatening hypoxaemia.

A recent paper has looked into some of the controversies surrounding RM.[25] Patients who responded transiently to RM were recruited adequately but were subsequently ventilated with inadequate PEEP while patients who had sustained improvement in oxygenation were ventilated with adequate PEEP after their RM. RM's may not help when it is applied late in ARDS or when inadequate pressures are applied during a RM.

Conclusions regarding RM

Current evidence suggests that RM should not be used in all patients with ARDS unless they have severe refractory hypoxaemia. In patients with severe refractory hypoxaemia, RMs should be used early as a rescue manoeuvre to open the lung when setting PEEP or following evidence of acute lung derecruitment such as ventilator circuit disconnection.

Objective assessment of lung recruitment and optimal PEEP

Various techniques have been used to objectively assess lung recruitment. Borges *et al* showed that the combined value of $PaO_2 + PaCO_2$ of more than 400 indicated complete recruitment.[26] Hodgson and colleagues showed that the PaO_2/FiO_2 ratio correlated with systemic saturation and lung compliance during lung recruitment manoeuvres.[20] In another study, changes in dynamic compliance correlated well with changes in FRC and dead space.[27] In a piglet model, Hanson and colleagues showed that maximal tidal elimination of CO_2 ($VTCO_2$) correlated with complete lung recruitment while a drop in dynamic compliance during decremental PEEP trial correlated with lung derecruitment.[28]

Caramez compared various techniques including maximum PaO_2, minimum $PaCO_2$, combined PaO_2 + $PaCO_2$, $P_{flex.i}$, upper deflection point, $P_{mci.i}$ and $P_{mcd.d}$ to identify optimal PEEP *(Figure 3)*.[29] They found no statistically significant difference between any of these variables. The PEEP obtained with the point of maximum deflation on expiratory limb and points of maximal compliance decrease (expiratory limb) were significantly higher while the $P_{flex.i}$ and minimum $PaCO_2$ were significantly lower than other variables.

A theoretical advantage of using an objective based assessment of lung recruitment is that an occasional patient may require less recruitment pressure than the arbitrary value, or more likely, the lungs may not be fully recruited with the target values that have been used.

Clinical application of RM and setting of PEEP

A practical way of applying RM in the clinical setting is to set the patient on PCV after deep sedation or paralysis of patient. The PEEP is set at 20 cm H_2O and the PC level at 40 cm H_2O. The RM is carried out for 2-3 min based on patient tolerance. After the RM, the patient is changed to VCV at 6 mL/kg or less and a decremental PEEP trial is applied. The VCV is used at this point because most modern ventilators instantaneously give the lung compliance on this mode. The patient is allowed to stabilise at this level of PEEP. Compliance stabilises in 3-5 min. The PaO_2 or PaO_2 + $PaCO_2$ may also be used to identify the optimal PEEP. The PEEP is then reduced in steps of 2 cm H_2O till a drop in compliance or any of the other parameters is noticed. Once the critical closing pressure is identified, a repeat RM is done and the PEEP is set 2 cm H_2O above the critical closing pressure. The RM can be tried at a higher PEEP and pressure control levels in case adequate recruitment is not appreciated.

New concepts in PLV

The stress index

The stress index utilises the patient's pressure time wave form during constant flow generated, volume controlled ventilation, to reflect tidal recruitment and overdistention. *Figure 4* shows the three basic shapes: the upward sloping convex shape suggesting alveolar overdistention (stress index < 1), the upward sloping concave shape suggesting suboptimal ventilation (stress index > 1) and the straight line implying no further recruitment or overdistention. Grasso and colleagues using stress index revealed significant overdistension in patients managed with ARDS Net protocol and stress index based management resulted in better lung compliance and minimal release of inflammatory mediators.[30]

Targeting transpulmonary pressure

The airway pressure is affected by chest wall compliance, respiratory muscle activity and intra-abdominal pressure. The transpulmonary pressure [PTP (airway pressure – pleural pressure)] is however, unaffected by the above factors as well as any intra-alveolar pathology. PTP reflects the actual lung distending pressure.[31] In clinical practice, this is estimated by a balloon catheter placed in the oesophagus. Talmor and colleagues compared PTP guided ventilation *versus* traditional ARDS network based ventilation in 61 patients with ARDS.[32] PTP guided ventilation resulted in higher PaO_2/FiO_2 and better lung compliance than traditional practice. Grasso and colleagues in a similar study showed that PTP rather than unadjusted airway pressure guided the optimum PEEP required while keeping the end inspiratory PTP within acceptable limits.[33] Among 14 patients with severe H1N1 infection referred for extra corporeal membrane oxygenation (ECMO), the authors found seven patients whose P_{plat} was below acceptable levels. In these patients optimisation of PEEP levels resulted in improved oxygenation and avoidance of ECMO.

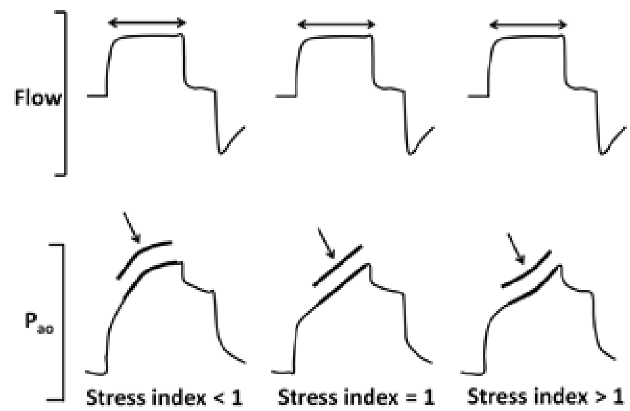

Figure 4: Stress index. Evaluation of pressure time waveform on constant flow generated volume control ventilation. Stress index < 1 indicates alveolar over-distension, Stress index > 1 indicated alveolar under filling and stress index of 1 indicates adequate alveolar filling.

Summary

Traditional ventilation with large tidal volumes can result in barotrauma, atelectrauma and volutrauma. PLV using low V_T and optimal PEEP has shown the best outcome in patients with ARDS. In a clinical setting, the ideal PEEP can be identified through the P-V loop or drop in compliance. High PEEP should be used only in patients with severe hypoxaemia. It should not be tried in patients with ALI. Recruitment manoeuvres may be used only as rescue therapy. Objective assessment should be used for evaluating lung recruitment. PLV cannot always salvage patients and alternative modes of ventilation or therapy should be tried in case of failure. Recent concepts such as the PTP and stress index may become more practical in the coming years.

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