Current strategies for mechanical ventilation in acute lung injury

THE PROBLEM WITH MECHANICAL VENTILATION

Non-invasive modes of ventilation may be adequate for some patients with less severe acute lung injury (ALI) but invasive positive pressure ventilation is usually required. Ventilation strategies for such patients have changed significantly in recent years, as it is has become increasingly apparent that the process of ventilation itself may contribute to lung injury.

Pulmonary and thoracic compliance are often severely reduced in ALI and high peak airway pressures (PAW) have been employed in an attempt to recruit lung units and hence, improve tidal volume (VT)/CO_2 clearance and oxygenation. Positive end-expiratory pressure (PEEP) is also applied to keep alveoli open and prevent de-recruitment during expiration. This can be applied as extrinsic PEEP by the ventilator or, alternatively, intrinsic or auto PEEP can be encouraged by reducing the expiratory time relative to the inspiratory time, so-called reverse-ratio ventilation.

These manoeuvres may lead to excessive PAW, and barotrauma is perhaps the most commonly recognized form of ventilator-induced lung injury (VILI). However, there is significant experimental and clinical evidence to suggest that other mechanisms may contribute to VILI including:

- Oxygen toxicity — high fractional inspired oxygen concentrations (FiO_2) produce ALI within hours in experimental models
- Over-distension injury ('volutrauma') — ventilation at high PAW or high VT are well established models of early ALI
- Shear stress and biotrauma — forces generated between lung units of differing compliance may lead to injury to the alveolar–capillary membrane. More recent observations also suggest the activation of inflammatory pathways during mechanical ventilation in animals and in humans.

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THE DILEMMA

Ventilation in acute lung injury: what is the best strategy?

LOW TIDAL VOLUME VENTILATION

Avoiding high airway pressures and over-distension, coupled with adequate and sustained alveolar recruitment would appear to be a reasonable approach to protect the lung from VILI. A number of studies have examined the use of a low VT strategy. The largest is a recently published multi-centre randomized, controlled trial conducted by the ARDSnet group in the USA (The Acute Respiratory Distress Syndrome Network, 2000). The strategy used is summarized in *Figure 1*.

The study involved 861 carefully selected patients with ALI who were randomized to receive volume-controlled ventilation at either 6 ml/kg body weight or 12 ml/kg. A 20–25% reduction in mortality was observed in the 6 ml/kg group. It is important to note that other ventilation parameters were tightly controlled in this study. In particular, PEEP was titrated according to FiO_2 (*Figure 1*). These levels of PEEP are higher than traditional values and may also have contributed to the effect observed (see below).

POSITIVE END-EXPIRATORY PRESSURE

ALI is a heterogeneous process and compliance will vary between alveolar

1. Set tidal volume (VT) to 8 ml/kg
2. Reduce VT by 1 ml/kg every 1–2 hours until 6 ml/kg
3. Set flow rate above patient demand (usually > 80 litres/min)
4. Oxygenation goal: PaO_2 7–10 Kpa or SpO_2 >88%. FiO_2/PEEP incremented as below:

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1.0	1.0	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	20	22	24

5. Plateau pressure (Pplat) goal.
   a. If Pplat>30 cmH_2O: decrease VT by 1 ml/kg steps (min 4 ml/kg)
   b. If Pplat<25 cmH_2O: increase VT by 1 ml/kg until Pplat <25 cmH_2O or VT>6 ml/kg
6. pH goal.
   a. If pH = 7.15–7.30: increase RR until pH>7.30
   b. If pH < 7.15: increase RR to 35, increase VT in 1 ml/kg increments and consider $NaHCO_3$

Figure 1. ARDSnet low tidal volume ventilation strategy. From the Acute Respiratory Distress Syndrome Network (2000)

units. The successive recruitment and derecruitment of relatively compliant alveoli could lead to abnormal shear stresses between these and adjacent alveoli with a lower compliance. Understanding possible solutions to this problem requires reference to the dreaded pressure–volume (P–V) curve (*Figure 2*).

When a static P–V curve is determined for an individual patient, a lower flexion point for the inspiratory limb can usually be identified as the point of greatest change in the slope of the curve (*Figure 2*, point A). This is believed to represent the point at which alveolar opening occurs. Setting the level of extrinsic PEEP above this value might avoid de-recruitment and there is some clinical evidence for this approach; in a recent study, a low VT strategy in combination with high PEEP produced a mortality benefit in patients with ALI. This strategy is now the subject of a much larger multicentre trial by the ARDSnet group.

At the upper end of the inspiratory curve is a point at which little or no further recruitment occurs despite increasing pressure (*Figure 2*, point B). Increasing pressure beyond this upper flexion point is likely to increase the risk of barotrauma. This had led to the concept of a safe-zone for ventilation between the upper and lower flexion points.

It is also apparent from P–V curves that a similar volume of lung may be 'open' or recruited during expiration, with a lower airway pressure than that required during inspiration. This has lead to the use of recruitment manoeuvres designed to maximally recruit alveoli at the minimum pressure (*Figure 2*, point C).

One example is the temporary application of very high PEEP (30–50 cm H_2O) for 1–2 minutes, followed by a reduction to previous levels. There are significant limitations to both the measurement and interpretation of P–V curves. They require considerable expertise and equipment, and the techniques for measurement and interpretation remain hotly debated. They remain experimental tools at present. For example, recent evidence suggests that alveolar recruitment continues to occur above the lower flexion point.

HIGH FREQUENCY OSCILLATORY VENTILATION

Although used extensively in neonates and small children, high frequency oscillatory ventilation (HFOV) has only recently been possible in adults with commercially available ventilators. HFOV uses high respiratory rates (60–2000 breaths/minute) and low VT (1–4 ml/kg) and could, in theory, be a useful approach in ALI. The only published data in such patients is limited to a single case series. This at least demonstrates feasibility but at present HFOV is a promising but untested technique for the future.

SO, WHAT DOES AN INTENSIVIST DO?

Patients should be ventilated at a lower VT (6–8 ml/kg) than traditionally used. It is also likely that the use of high PEEP (10–20 cm H_2O) will be beneficial. Limiting the FiO_2 to below 0.6 would seem a reasonable target, although the clinical evidence for this is weak at present. The strategy used in the ARDSnet study is therefore a good starting point.

Of course, limiting PAW and/or VT may lead to both a rise in $PaCO_2$ and a potential reduction in PaO_2. Consequently, adopting a 'lung protection' strategy has forced us to reevaluate the targets for 'adequate' gas exchange.

Many intensive care units now allow permissive hypercapnoea (pH >7.20 or $PaCO_2$ 7–10 kPa) and permissive hypoxia (PaO_2 of 7–10 kPa). Permissive hypercapnoea, as employed in the recent ARDSnet study, appeared to be well tolerated, although a relative minority of patients were hypercapnoeic in this study, largely as a result of increases in respiratory rate. Better indices of end-organ response are now required for us to further define the acceptable limits for these parameters.

Undoubtedly, the way we that we ventilate patients with ALI will continue to evolve. This is likely to occur in conjunction with an increasing individualization of ventilation strategy based on mechanical, radiological and biological measurements. HM

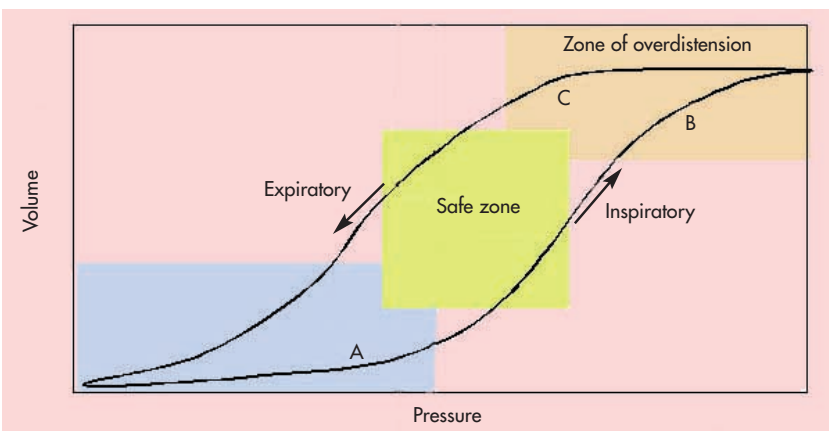

Figure 2. The safe zone.

The Acute Respiratory Distress Syndrome Network (2000) Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* **342(18)**: 1301–8

Further reading

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Dreyfuss D, Saumon G (1993) Role of tidal volume, FRC, and end-inspiratory volume in the development of pulmonary edema following mechanical ventilation. *Am Rev Respir Dis* **148(5)**: 1194–203

Tobin MJ (2000) Culmination of an era in research on the acute respiratory distress syndrome. *N Engl J Med* **342(18)**: 1360–1

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