Recruitment manoeuvres in acute respiratory distress syndrome: Little evidence for routine use

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The use of alveolar recruitment manoeuvres for the treatment of acute respiratory distress syndrome is a topic of uncertainty in current critical care practice. Acute respiratory distress syndrome leads to inflammatory atelectasis, which challenges the gas exchange properties of the lung. Recruitment of atelectatic lung tissue requires elevation of transpulmonary pressure. Transpulmonary pressure can be suppressed at a given airway pressure when pleural pressures are elevated. The present review discusses recruitment of lung tissue in detail, highlighting the key research in the field. Differing techniques for recruiting lung tissue, as well as various outcome measures to determine efficacy, are analyzed and critiqued. The commonly used sustained inflation manoeuvre is perhaps regarded as the only strategy to recruit the lung, explaining its prevalence. Staircase recruitment with positive end-expiratory pressure titration is shown to be an equally – if not more – effective therapy that devotes attention to the maintenance of lung recruitment.

Key Words: *Acute respiratory distress syndrome; Lung mechanics; Lung recruitment; Recruitment manoeuvre; Transpulmonary pressure*

Les manœuvres de recrutement en cas de syndrome de détresse respiratoire aiguë : peu de données probantes pour une utilisation systématique

L'utilité des manœuvres de recrutement alvéolaire pour traiter le syndrome de détresse respiratoire aiguë demeure incertaine en soins aigus. Le syndrome de détresse respiratoire aiguë entraîne une atélectasie inflammatoire qui nuit aux propriétés d'échange gazeux des poumons. Pour recruter les tissus pulmonaires atélectasiques, il faut élever la pression transpulmonaire. On peut supprimer la pression transpulmonaire à une pression donnée des voies aériennes lorsque les pressions pleurales sont élevées. La présente analyse traite en détail du recrutement des tissus pulmonaires et fait ressortir les recherches clés dans le domaine. Les chercheurs analysent et critiquent diverses techniques de recrutement des tissus pulmonaires, de même que diverses mesures d'issue pour en déterminer l'efficacité. La manœuvre d'inflation courante est peut-être considérée comme la seule stratégie de recrutement des poumons, ce qui en expliquerait la prévalence. Les chercheurs démontrent que le recrutement par paliers à l'aide du titrage de la pression positive en fin d'expiration est un traitement tout aussi efficace, sinon plus, qui est entièrement axé sur le maintien du recrutement pulmonaire.

The use of alveolar recruitment manoeuvres (RMs) is a topic of uncertainty in the management of the hypoxemic respiratory failure found in acute respiratory distress syndrome (ARDS). An RM is a deliberate application of elevated transpulmonary pressure (airway pressure – pleural pressure) intended to reopen previously collapsed lung units, thus increasing the surface area available for gas exchange. It is also suggested that recruiting collapsed lung tissue enables a more homogeneous distribution of ventilation throughout the lung, reducing ventilator-induced lung injury (1,2). Acutely injured lungs have been shown to consist of heterogeneous regions of aerated and collapsed alveoli. Morphologically, ARDS is characterized by inflammatory atelectasis, causing considerable reduction in functional residual capacity (3) and air-to-tissue ratio. A computed tomography study published in 2000 (3) reported a 17% reduction in end-expired lung volume in ARDS patients versus healthy volunteers. This alveolar collapse (ie, atelectasis) has been attributed to increased interstitial pressure and the compressive forces of the weight of the lung. This atelectasis can be worsened by factors such as obesity, high abdominal pressure, disconnections from the ventilator and tracheal suctioning (4). Furthermore, ventilation of acutely injured lungs with positive pressure leads to the generation of shearing forces at the junctions of aerated (compliant) and nonaerated (noncompliant) lung units, inducing lung injury (1).

Recruitment of lung tissue is believed to minimize ventilator-induced lung injury by two mechanisms. First, alveolar recruitment increases the aerated lung mass, thus promoting a homogenous distribution of ventilation. This minimizes shearing forces at the junctions of inflated and underinflated lung units. Lachmann (5) introduced this notion in a 1992 editorial titled 'Open the lung and keep the lung open', explaining that at a transpulmonary pressure of 30 cmH_2O, the shearing forces at the junction of an atelectatic region surrounded by a fully recruited lung region can exceed 140 cmH_2O, a pressure very likely to induce barotrauma. Second, obtaining appropriate alveolar recruitment minimizes the cyclic opening and closing of terminal lung units (4).

Recent randomized controlled trials and systematic reviews have been unable to demonstrate a significant benefit to support the routine use of RMs in the management of ARDS (6-9). The most recent systematic review on this topic was published in 2009 (7). A Cochrane Review also published in 2009 (10) concluded there was no evidence that RMs reduce mortality or length of ventilation in ARDS patients. The use of RMs in ARDS patients remains a topic of clinical interest and investigation. The purpose of the present review is to synthesize the literature published since the last systematic review, and identify some of the potential barriers encountered when implementing RMs in clinical practice.

There is an observed variability in the response to RMs in patients with ARDS, and investigation into the cause of such variation is an active area of research. One hypothesis is that the degree of extravascular lung water (pulmonary edema) significantly influences the response to RMs (11). Smetkin et al (11) found that of the 17 patients who received a sustained inflation RM (40 cmH_2O for 40 s), only five showed a significant response, defined as a 20% increase in the ratio of partial pressure of oxygen (PaO_2)/fraction of inspired oxygen (FiO_2) from baseline. Additionally, this response was not sustained in 58% of patients, suggesting alveolar recruitment was short lived. Edema was a predictor of RM response, with patients with pulmonary edema showing no significant response to RMs. Individuals without pulmonary edema demonstrated a 33% increase in PaO_2/FiO_2 after RMs (11). Lung morphology is also considered to be a significant factor, not only in the response to RM, but in the severity of adverse effects. A recent computed tomography study (12) performed imaging on early ARDS patients at four stages surrounding an RM while identifying the specific lung morphology present. The patients were categorized as having either focal lung morphology ('lobar' loss of aeration predominantly to lower lobes) or nonfocal lung morphology (defined as either patchy or diffuse loss of aeration). Lung morphology impacted the response to RM. Only patients with nonfocal lung morphology showed a significant improvement in arterial oxygenation, the chosen

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outcome predictor. Patients with focal lung morphology were found to have a smaller potential for alveolar recruitment, with lung hyperinflation predominant over lung recruitment. A hyperinflated lung can reach up to 24% of total end-expired lung volume in patients with focal lung morphology (this would likely be much greater at end inspiration). Furthermore, the hyperinflated lung can remain elevated at up to 10% of total lung volume after a post-RM steady-state, implying that RM-induced hyperinflation can cause some degree of airspace enlargement secondary to alveolar wall damage (12). This heterogeneity in distribution of recruitment volume has been shown to impact the incidence of complications. In the largest clinical study on RMs to date, Fan et al (13) found that primary focal consolidation was associated with marginal lung recruitability and a higher complication rate when compared with more diffuse morphologies apparent in extrapulmonary processes. This is consistent with animal data showing that RMs are more effective at recruiting collapsed lung tissue in extrapulmonary lung injury than direct pulmonary lung injury (14). The number of RMs applied was also significantly associated with incidence of complications (13). These findings suggest considerable caution be exercised when performing RMs routinely on ARDS patients without knowledge of the baseline morphology. This also seriously questions the application of a 'one-size-fits-all' therapeutic intervention to a demonstrably diverse disease population.

Alveolar recruitment can be achieved using a variety of techniques, and lack of standardization in this regard acts as a barrier to widespread use in critical care. The ideal technique would provide sustainable alveolar recruitment to correct and prevent hypoxemia, and improve lung mechanics (improving ventilation) while having a low incidence of complications/adverse effects. Additionally, to increase the potential for widespread implementation, an ideal RM would not be complicated and time consuming to perform. The most prevalent technique is the sustained inflation (SI) RM, which uses a sustained elevation of plateau pressure in a continuous positive airway pressure with pressure support mode. The pressure support is set to zero and the continuous positive airway pressure is elevated to the desired recruitment pressure (often 30 cmH_2O to 45 cmH_2O) for a given period of time (often 20 s to 45 s) (9,11,12,14-16). SI RMs have shown a transient improvement in oxygenation and respiratory mechanics (8,11,14); however, these improvements appear to be short-lived and associated with various adverse effects such as desaturation, hemodynamic instability and hyperinflation (9,11-13,15,16). There is evidence to suggest that the vast majority of recruitment (up to 98%) occurs within the first 10 s of an SI RM, with any additional inflation time providing insignificant benefit while triggering/worsening cardiovascular depression (15,16). It is certainly possible that the prevalence of this technique is based on lack of knowledge of alternative strategies and, thus, regarded as the only option. This method has the potential to overlook the complicated lung mechanics found in ARDS. As mentioned, recruitment is achieved by elevation of transpulmonary pressure, not merely airway pressure. Esophageal balloon measurement has estimated that the average pleural pressure in an ARDS patient is 17 cwp (17). The resulting transpulmonary (recruiting) pressure applied during a '40-for-40' trial would then be reduced to only 23 cwp, a pressure unlikely to exceed the critical opening pressure of unstable lung units. Piraino (18) elegantly demonstrated this concept at a recent respiratory therapy conference by showing images of balloons inflated within pressurized 18.5 L water jugs. Increasing the pressure in the jug mimics increased pleural pressure, thus reducing balloon inflation at a given pressure as the balloon 'feels' a lower distending (transpulmonary) pressure. The mounting data regarding esophageal balloon pressure as a surrogate for pleural pressure may justify investigation into the causes of high pleural pressure, and strategies to identify patients at a higher risk, improving our ability to individualize protective ventilation.

A more recent RM technique involves ventilation with pressure control ventilation with progressively increasing positive end-expiratory pressure (PEEP). Staircase recruitment manoeuvres (SRM) with PEEP titration provides 15 cmH_2O of pressure control above PEEP, while increasing PEEP from 20 cmH_2O to 30 cmH_2O, to 40 cmH_2O every 2 min, reaching a maximum peak pressure of 55 cmH_2O. PEEP is then titrated at 3 min intervals to 25 cmH_2O, 22.5 cmH_2O, 20 cmH_2O, 17.5 cmH_2O, to a minimum of 15 cmH_2O until an oxygen saturation decrease of 1% to 2% is observed. This is defined as the derecruitment point. The lung is then re-recruited before the 'optimal PEEP' is set at 2.5 cmH_2O above the derecruitment point (19). This approach has been found to be safe and effective in up to 80% of early ARDS patients (19). Of interest, this success rate is higher than found in the literature for SI manoeuvres. Concerns regarding SRM tend to focus on the potential adverse effects of higher ventilating pressures. However, returning to the physiology of transpulmonary pressure versus airway pressure may suggest they are a necessity. LaPlace's law also provides explanation as to why atelectatic lung regions require higher distending pressures, as Lachmann (5) stresses in a previously mentioned editorial. Hodgson et al (20) found that although 40% of patients experienced transient desaturation, this did not preclude a positive response to the RM. This is noteworthy because desaturation is typically an indication for termination of the RM, and interpreted as a RM failure in the literature to date, which may explain the lower percentage success rate observed. The data presented in the study by Hodgson et al (20) demonstrate that transient desaturation is well tolerated, with many patients still showing significant improvement from the RM. Open lung ventilation with SRM and permissive hypercapnia has demonstrated improvement in inflammatory markers, PaO_2/FiO_2 and static lung compliance, as well as decreased time on the ventilator compared with the ventilatory strategy defined by the ARDS Network protocol (19,21). There are also trends toward shorter intensive care unit and hospital stay with the aforementioned strategy, although trials to date have not been powered to demonstrate statistical significance (19). It is, however, worth highlighting some methodological differences in the literature around recruitment and PEEP titration. Oxygenation alone may not be the best predictor of optimal PEEP/recruitment. Studies to date have used a variety of outcome measures to determine optimal recruitment with little consistency. Lung compliance and deadspace fraction have been discussed as equally valuable outcome predictors. Striving for the highest PaO_2/FiO_2 ratio may come at the expense of more optimal lung mechanics, and may provide explanation for the lack of robust data for clinically relevant outcomes. Borges et al (22) compared SI RM (40 cmH_2O for 40 s) with an SRM similar to the previously described technique. Oxygenation was significantly improved in the SRM group compared with the SI group. The use of high airway pressures (>35 cmH_2O to 40 cmH_2O) was necessary to achieve this improved recruitment. This came at a cost because transient hemodynamic depression occurred in some patients, although no significant clinical consequences were observed. They concluded that the widely used SI method was 'suboptimal' when compared with the SRM method.

Recruitment of collapsed lung units is a key strategy in the management of hypoxemia in ARDS. What is needed is large-scale investigation into standardizing RM technique and indications, as well as outcome predictors that encompass lung mechanics, not merely oxygenation. It is clear from the present review that RMs are not a one-size-fits-all therapy. Lung morphology greatly influences the response to RMs, and predicts the degree of hyperinflation and airspace damage caused by high transpulmonary pressures (12). SRM with PEEP titration may be a more effective strategy than SI manoeuvres; recent evidence supports this inference (22). The potential implementation of SRM to supplement or replace the favoured SI manoeuvres will require education of clinicians because the technique is more complicated and time consuming than the SI manoeuvre, and often reaches more worrying peak airway pressures (19,20,22). It is certainly arguable that the evidence to support SRM is not sufficiently robust to change practice. The use of SRMs is a growing area of investigation, with only a few well-conducted studies published. It should be considered, however, that the current therapy (SI manoeuvres) are by no means a gold standard to surpass. The present review has shown that the literature pertaining to SI manoeuvres has essentially shown no impact on mortality. Perhaps, then, the implementation of a different technique of potentially greater benefit is positive. More institutions adopting SRMs would, at minimum, provide a platform for more widespread investigation of the technique, potentially providing the data needed to support SRM use. The present literature search did not find any articles that addressed the increased time factor associated with performing SRM over SI manoeuvres. When performed appropriately, the SRM can take up to 25 min for the clinician (likely a respiratory therapist) to perform, potentially necessitating greater staffing. Clinicians should also familiarize themselves with the data regarding who may benefit from the manoeuvres and, importantly, who will experience a worsened lung injury. Larger randomized controlled trials that are powered to demonstrate clinically relevant outcomes (mortality) are warranted based on recent evidence. Smaller studies have shown promising trends toward such outcomes, but have not had the quantity of data required to achieve statistical significance (20,21).

SUMMARY

The key messages of the present review are that recruitment of the atelectatic lung tissue of ARDS is based on the degree of transpulmonary pressure applied. High pleural pressure reduces transpulmonary pressure at a given airway pressure, reducing recruitment. Tools, such as esophageal balloon measurement, can be used to accurately predict pleural pressure, allowing for more individualized PEEP application. Maintenance of recruitment after effective lung inflation is paramount to protective ventilation and recruitment without attempt to obtain optimal PEEP has only shown short-lived improvements. At this time, the routine use of RMs in the management of ARDS remains unsupported by evidence.

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