Commentary
How best to recruit the injured lung?

John J Marini

Pulmonary and Critical Care Medicine, Regions Hospital, University of Minnesota, Minneapolis/St Paul, MN 55101, USA

Corresponding author: John J Marini, marin002@umn.edu

Published: 20 June 2008
This article is online at http://ccforum.com/content/12/3/159

Critical Care 2008, **12:**159 (doi:10.1186/cc6910)

See related research by Constantin *et al*., http://ccforum.com/content/12/2/R50

Abstract

Sustained re-opening of collapsed lung tissue (recruitment) requires the application of airway pressures that exceed those of the tidal cycle. The post-maneuver PEEP as well as the duration of high pressure application are also key factors in its success, with their accompanying potential for hemodynamic compromise. Although a wide variety of recruiting maneuvers have been described, the technique that strikes the best balance between efficacy and risk may well vary among patients with differing right heart loading status and lung properties.

‘Opening’ of airless units, or recruitment, not only improves pulmonary gas exchange, but also tends to limit tissue stress and ventilator-induced lung injury when the lung is repeatedly exposed to high end-inspiratory tidal pressures. Illustrated in the paper by Constantin and colleagues that appears in the previous issue of *Critical Care* [1], successful recruiting techniques recognize that sustained benefit depends not only on the magnitude of transpulmonary pressure applied during recruitment, but also on the duration and pattern of its application [2-5], and the level of post-recruitment positive end-expiratory pressure (PEEP) [6,7]. As computed tomography demonstrates, uniformly (as opposed to patchily) injured lungs are more likely to respond to interventions geared to restore patency of collapsible airspaces [8]. Because of viscoelastance and other time-dependent force-distributing phenomena, the tendency of a previously collapsed airway to open (or ‘yield’) is a function of both transpulmonary pressure and time [9]. Multiple cycles that reach the same peak pressure may be needed to achieve the full effect.

Specialized ‘recruitment’ maneuvers (RMs) such as intermittent sighs, sustained applications of high pressure and brief exposures to increased PEEP with preserved tidal volumes or driving pressure acknowledge this interplay of high airway pressure and duration of its application. Because some lung units open at pressures that exceed those normally encountered during tidal breathing, RMs are especially helpful when the tidal ventilation pattern that precedes them involves low end-inspiratory pressures, as during small tidal volume (‘lung protective’) ventilation. Conversely, RMs cannot be expected to have an impressive result if nearly all potentially recruitable tissue has already been opened and kept patent by PEEP or by favorable body orientation. Prone positioning should be considered a form of RM [10]. As the weight of the heart is relieved from the dependent portions of the lungs and the pleural pressure gradient redistributes, trans-alveolar forces increase in the dorsal zones of the lung. Once the patient has been re-positioned, these forces are sustained, helping to maintain patency of alveoli that are opened by increased local pressure.

‘Biologically variable’ and ‘noisy’ ventilatory patterns have been reported to achieve better oxygenation than does a monotonously uniform pattern of unchanging tidal volume associated with the same minute ventilation [11-13]. The contribution of irregularity of these patterns remains of uncertain significance. Thus, whether it is biological variability or just periodic achievement of high pressure amplitude that benefits patients remains to be determined.

Because recruitment occurs to some extent throughout most of the lung capacity range, applying high pressure to open the lung is always a trade-off between over distending some units and recruiting others. A wide variety of RMs have been described; the best technique is currently unknown and may well vary with specific circumstances. The work of Constantin and colleagues [1] illustrates that not all RMs are equivalent, either from the standpoint of efficacy or adverse side effects. Although a reasonable RM is unlikely to damage the lung, the risk of hemodynamic compromise occurring during and for a short while after the maneuver is considerable, especially with sustained high inflating pressure applied to less recruitable

PEEP = positive end-expiratory pressure; RM = recruitment maneuver.

lungs [14,15]. When sustained pressure is applied without relief, mean and peak airway pressures become equivalent. This elevation of mean airway pressure imposes an extraordinary backpressure to impede venous return and presents a high afterload to the right ventricle for the period of its application. Successful recruitment tends to minimize the peril. The prior work of Grasso and colleagues [14] and Lim and colleagues [15] accords nicely with that of Constantin and colleagues [1] in highlighting such hemodynamic issues and in illustrating that intermittent high pressure is better tolerated than sustained high pressure. In experimental models, pneumonia appears to be the condition with greatest risk for hypotension during the RM [15].

Mean airway pressure can be reduced considerably while maintaining the same peak airway pressure value - the airspace component of the actual recruiting pressure - by applying tidal ventilation with a high plateau pressure for a brief period (for example, pressure controlled ventilation). Because pressures exceeding 60 cmH_2O may be required to re-open some units [16], it is clear that 'tidal' forms of recruitment are more likely to be both successful and well tolerated than sustained inflation. Once opened, the applied end-expiratory pressure should be released in stages, using oxygenation and/or expiratory deflation mechanics to identify the appropriate PEEP that sustains nearly full recruitment. Almost invariably, that sustaining level of post-recruitment PEEP is higher than the initial value.

Before we embrace the 'open lung' concept and its indispensable instrument of RMs, it is important not only to understand the principles of recruitment but also to ask whether open lung techniques should be applied - and to whom. Opening and closure of lung units may not always be harmful. For example, when relatively low pressures are required to ventilate effectively and surfactant function is well preserved, any lung damaging effect of tidal opening and closing should be modest. Airless tissue is not likely to be subject to ventilator-induced lung injury - the adjacent healthy lung is. In many instances the pressure cost of recruitment may exceed the benefit of recruiting a few more units. Apart from initial PEEP selection, where RMs are essential, RMs are logically reserved for instances in which deterioration of oxygen exchange or mechanics has been observed (as after airway suctioning) or a new clinical event requires adjustment of PEEP and tidal volume. Based on its apparent efficacy and safety, the extended sigh reported by Constantin and colleagues [1] may be one attractive option.

Competing interests

The author declares that they have no competing interests.

References

1. Constantin J-M, Jaber S, Futier E, Cayot-Constanitn S, Verny-pic M, Yung B, Bailly A, Guerin R, Bazin J-E: **Respiratory effects of different recruitment maneuvers in acute respiratory distress syndrome.** *Crit Care* 2008, **12:**R50.
2. Lapinsky SE, Aubin M, Mehta S, Boiteau P, Slutsky AS: **Safety and efficacy of a sustained inflation for alveolar recruitment in adults with respiratory failure.** *Intensive Care Med* 1999 **25:** 1297-1301.
3. Foti G, Cereda M, Sparacino ME, De Marchi L, Villa F, Pesenti A: **Effects of periodic lung recruitment maneuvers on gas exchange and respiratory mechanics in mechanically ventilated acute respiratory distress syndrome (ARDS) patients.** *Intensive Care Med* 2000, **26:**501-507
4. Fujino Y, Goddon S, Dolhnikoff M, Hess D, Amato MB, Kacmarek RM: **Repetitive high-pressure recruitment maneuvers required to maximally recruit lung in a sheep model of acute respiratory distress syndrome.** *Crit Care Med* 2001, **29:**1579-1586
5. Rimensberger PC, Pache JC, McKerlie C, Frndova H, Cox PN: **Lung recruitment and lung volume maintenance: a strategy for improving oxygenation and preventing lung injury during both conventional mechanical ventilation and high-frequency oscillation.** *Intensive Care Med* 2000, **26:**746-747.
6. Lim CM, Koh Y, Park W, Chin J, Shin T, Lee S, Kim WS, Dong S, Kim WD: **Mechanistic scheme and effect of 'extended sigh' as a recruitment maneuver in patients with acute respiratory distress syndrome: a preliminary study.** *Crit Care Med* 2001, **29:** 1255-1260.
7. Lim S-C, Adams AB, Simonson D, Dries DJ, Broccard AF, Hotchkiss JR, Marini JJ: **Intercomparison of recruitment maneuver efficacy in three models of acute lung injury.** *Crit Care Med* 2004, **32:**2371-2377.
8. Puybasset L, Gusman P, Muller JC, Cluzel P, Coriat P, Rouby JJ: **Regional distribution of gas and tissue in acute respiratory distress syndrome. III. Consequences for the effects of positive end-expiratory pressure. CT Scan ARDS Study Group. Adult Respiratory Distress Syndrome.** *Intensive Care Med* 2000, **26:**1215-1227.
9. Gaver DP, Samsel RW, Solway J: **Effects of surface tension and viscosity on airway reopening.** *J Appl Physiol* 1990, **69:**74-85.
10. Cakar N, der Kloot TV, Youngblood M, Adams A, Nahum A: **Oxygenation response to a recruitment maneuver during supine and prone positions in an oleic acid-induced lung injury model.** *Am J Respir Crit Care Med* 2000, **151:**1949-1956
11. Mutch WA, Harms S, Ruth Graham M, Kowalski SE, Girling LG, Lefevre GR: **Biologically variable or naturally noisy mechanical ventilation recruits atelectatic lung.** *Am J Respir Crit Care Med* 2000, **162:**319-323.
12. Suki B, Alencar AM, Sujeer MK, Lutchen KR, Collins JJ, Andrade JS Jr, Ingenito EP, Zapperi S, Stanley HE: **Life-support system benefits from noise.** *Nature* 1998, **393:**127-128.
13. Gama de Abreu M, Spieth PM, Pelosi P, Carvalho AR, Walter C, Schreiber-Ferstl A, Aikele P, Neykova B, Hübler M, Koch T: **Noisy pressure support ventilation: a pilot study on a new assisted ventilation mode in experimental lung injury**. *Crit Care Med* 2008, **36:**818-827.
14. Grasso S, Mascia L, Del Turco M, Malacarne P, Giunta F, Brochard L, Slutsky AS, Marco Ranieri V: **Effects of recruiting maneuvers in patients with acute respiratory distress syndrome ventilated with protective ventilatory strategy.** *Anesthesiology* 2002, **96:**795-802.
15. Lim S-C, Adams AB, Simonson D, Dries DJ, Broccard AF, Hotchkiss JR, Marini JJ: **Transient hemodyvamic effects of recruitment maneuvers in three experimental models of acute lung injury.** *Crit Care Med* 2004, **32:**2378-2384.
16. Borges JB, Okamoto VN, Matos GF, Caramez MP, Arantes PR, Barros F, Souza CE, Victorino JA, Kacmarek RM, Barbas CS, Carvalho CR, Amato MB: **Reversibility of lung collapse and hypoxemia in early acute respiratory distress syndrome.** *Am J Respir Crit Care Med* 2006, **174:**268-278.