Intensive Care Med (2016) 42:908–911
DOI 10.1007/s00134-015-4025-5

Erica Aranha Suzumura
Marcelo Britto Passos Amato
Alexandre Biasi Cavalcanti

Understanding recruitment maneuvers

Received: 30 June 2015
Accepted: 7 August 2015
Published online: 20 August 2015

E. A. Suzumura (✉) · A. B. Cavalcanti
Research Institute-Hospital do Coração (HCor), Rua Abílio Soares, No 250, 12 andar, São Paulo, SP 04005-000, Brazil
e-mail: esuzumura@yahoo.com.br
Tel.: +55-11-3053 6611

E. A. Suzumura · A. B. Cavalcanti
Preventive Medicine Department, University of São Paulo, São Paulo, Brazil

M. B. P. Amato
Cardio-Pulmonary Department, Pulmonary Division, Heart Institute (InCor), University of São Paulo, São Paulo, Brazil

A recruitment maneuver (RM) is the process of inducing an intentional transient increase in transpulmonary pressure aimed at reopening non-aerated or poorly aerated alveoli. The immediate expected benefits are improvements in oxygenation and respiratory system compliance [1].

During an RM the transpulmonary pressure should overcome the critical opening pressure of at least a substantial proportion of closed alveoli. Once these alveoli are re-opened, pressure needed to avoid re-collapse is lower because during deflation a greater lung volume is achieved at a certain pressure level (Fig. 1a). The difference between pressure–volume (P–V) curves during inflation and deflation is the hysteresis. Thus, as long as positive end-expiratory pressure (PEEP) is kept above a critical pressure level, recruited alveoli will remain opened [1].

A series of patients with early acute respiratory distress syndrome (ARDS) receiving RM monitored by tomography showed that with zero end-expiratory pressure (ZEEP) there is a huge amount of collapsed alveoli at the gravitational-dependent lung zones [2]. With PEEP set 2 cmH_2O above the critical opening pressure, 20–30 % of the lung is still collapsed [2]. After RM achieving plateau pressures as high as 55 or 60 cmH_2O, less than 5 % of the total lung mass remains collapsed. The lungs showed less alveolar collapse on the deflation limb of the P–V curve (after RMs) when equivalent pressures were applied during the inflation (Fig. 1a).

The effect of RMs on oxygenation is marked [2, 3], thus RMs have a clear role as rescue therapy for patients with severe hypoxemia, refractory to protective ventilation strategies and prone position. Indeed, the LOV Study compared ventilation strategy including RM plus higher levels of PEEP to a control strategy with no recruitment and lower PEEP levels and showed decreased risk of death due to refractory hypoxemia in the experimental group [4]. It is important to note that most studies with RMs not followed by titrated PEEP observed rapid decline in PaO_2/FiO_2 [5]. Conversely, in patients ventilated with an optimal titrated PEEP after the RM, the oxygenation gains were sustained for days [2, 3].

Response to RMs is not homogenous in ARDS patients [6]. ARDS-associated fibroproliferation is more prevalent in late ARDS and may impair response to RMs; thus, although clear time cutoffs have not been established, these maneuvers are unlikely to benefit patients with more than 5 days of ARDS [7]. Other factors associated with

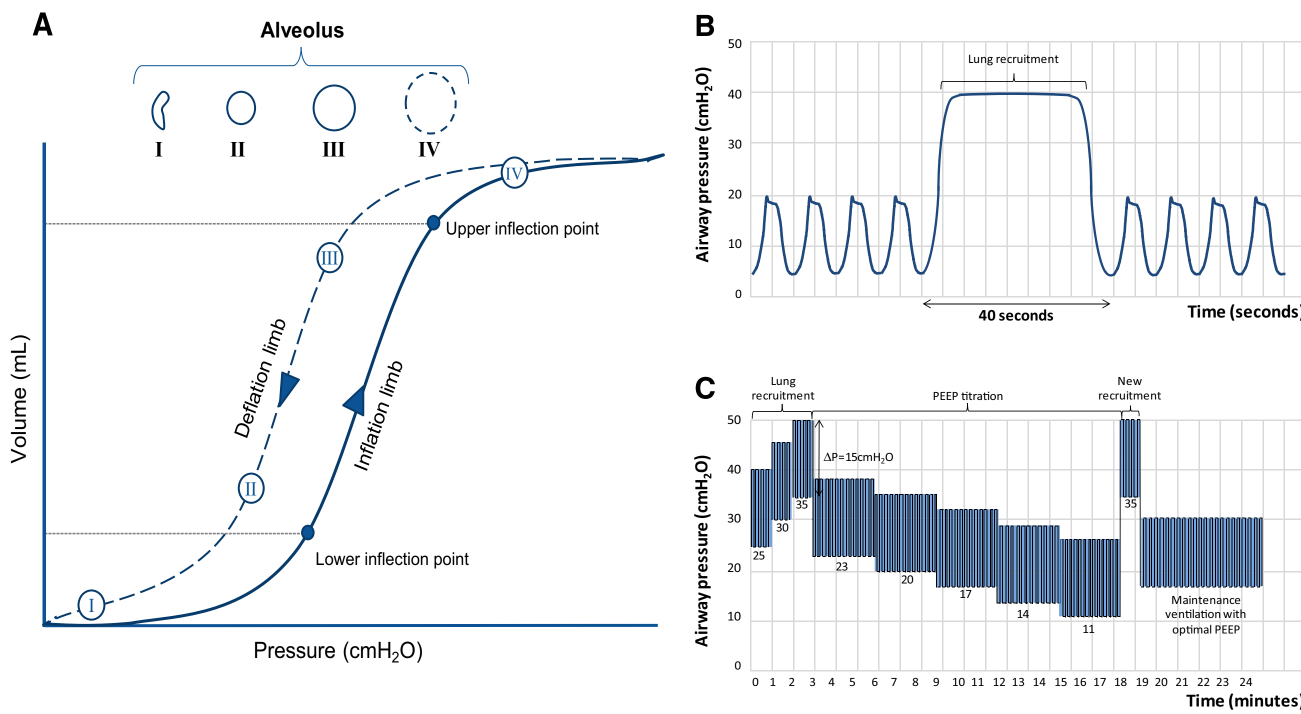

Fig. 1 Pressure–volume curve (**a**). During inflation (*full line*) transpulmonary pressure overcomes the critical opening pressure (upper inflection point). After recruitment maneuver, during deflation (*dotted line*), lung volume is greater at a certain pressure level, and alveoli remain opened as long as positive end-expiratory pressure (PEEP) is kept above a critical pressure level (lower inflection point). Pressure–time (seconds) curve (**b**) showing a sustained inflation recruitment maneuver using continuous positive airway pressure (CPAP) of 40 cmH_2O for 40 s. Pressure–time (minutes) curve showing a stepwise recruitment maneuver (**c**) using both inspiratory pressure and PEEP increases, keeping driving pressure fixed at 15 cmH_2O, achieving peak pressure after recruitment of 50 cmH_2O and PEEP of 35 cmH_2O. After recruitment, figure shows a decremental PEEP titration and a new recruitment maneuver performed after an optimal PEEP is identified (i.e., the PEEP associated with best compliance of respiratory system or best oxygenation). After the new recruitment, PEEP is set 2 cmH_2O above the optimal level

poorer response to RMs are more focal as opposed to diffuse morphology [8], higher PaO_2/FiO_2 ratios and respiratory-system compliance, and lower levels of dead space [6].

Although RMs are useful for improving oxygenation, only a few patients with ARDS die because of refractory hypoxemia [4]. Thus, a more relevant question is whether RMs may improve ventilator-induced lung injury (VILI) and clinical outcomes. The two independent main mechanisms of VILI are overdistention and atelectrauma, which is local shear injury attributed to cyclic opening and closing of distal small airways and alveoli [9].

Ventilation strategies using low tidal volumes but also low PEEP levels such as the ARDSNet protocol aim to prevent VILI by overdistention. However, this approach may lead to substantial cyclic opening and closing of alveolar units with worsening of VILI [9]. Positron emission tomography studies of experimental models of ARDS revealed that early inflammation is more pronounced in intermediate gravitational zones corresponding to normally or poorly aerated regions, as opposed to posterior collapsed or anterior overdistended zones [10]. These findings suggest that tidal stretch is a major mechanism in VILI. Indeed, experimental models of ARDS have shown that keeping higher PEEP levels may decrease further lung damage even when animals were ventilated at lower tidal volumes [9].

Alveolar fluid clearance is also impaired in most patients with ARDS [11]. Inhibition of fluid clearance is probably caused by hypoxia and by injured alveolar epithelium with disrupted cells. RMs may decrease lung edema, possibly by improving oxygenation and decreasing VILI [12].

Markers of inflammation and of alveolar epithelial type I cell injury decrease after RM and PEEP titration in ARDS [3, 13]. In addition, by re-opening collapsed alveoli, RMs can also increase respiratory system compliance and, as a consequence, reduce driving pressure which is the pressure needed to deliver a given tidal volume [14]. Finally, the reduction in driving pressure may ultimately improve survival of patients with ARDS [14].

Many RM techniques have been described, including sighs, sustained inflation, stepwise increase of inspiratory pressure and/or of PEEP. Intermittent sighs involves increasing tidal volume or level of PEEP for one of several breaths. Effectiveness of sighs is short-lived and they may lead to increased levels of inflammation markers [15]. Sustained inflation is the most commonly investigated method and involves use of continuous positive airway pressure (CPAP) of 40 cmH_2O for about 40 s (Fig. 1b) [5]. Compared with sustained inflation, methods involving stepwise increases in pressures lead to less hemodynamic compromise and less microscopic and biochemical signs of lung injury [16]. Furthermore, the best results in terms of recruitability have been obtained with stepwise increases in PEEP up to 45 cmH_2O with driving pressure fixed at 15 cmH_2O (Fig. 1c) [2].

RMs may be performed in supine or prone position. In the later case, RMs and prone position have additive effects on oxygenation and respiratory system compliance. This is important, since the use of prone positioning has become the standard of care for patients with ARDS and $PaO_2/FiO_2 \leq 150$ mmHg [17].

Although there is no standardization regarding the method to adjust PEEP after RMs, some method should be employed to identify a PEEP level capable of avoiding new collapse. A valuable bedside method, which does not require imaging, is decremental PEEP titration according to the best dynamic or static compliance [1]. Once the optimal PEEP is identified, lungs are recruited again, and PEEP is set 2 cmH_2O above the optimal level [1].

The effects of RMs on clinical outcomes have been assessed in a meta-analysis of ten randomized trials, which suggested that RMs may reduce hospital mortality without increasing the risk of barotrauma in patients with moderate or severe ARDS [18]. However, our confidence in the estimate of effect is low, especially because most trials are at high risk of bias. Another systematic review found that the common adverse events after RM are hypotension, acidosis, and desaturation, but they are usually self-limited and without serious sequelae [5].

In summary, there is uncertainty regarding the clinical effectiveness of RMs to improve clinical outcomes of ARDS patients. Ongoing multicenter randomized trials should provide a reliable answer to this question. Therefore, although there is a role for RMs as a rescue therapy in refractory hypoxemia in patients with moderate to severe ARDS, there is currently no solid basis for their routine use in other patients.

Compliance with ethical standards

Conflicts of interest The authors declare no conflicts of interest.

References

1. Kacmarek RM, Kallet RH (2007) Respiratory controversies in the critical care setting. Should recruitment maneuvers be used in the management of ALI and ARDS? Respir Care 52:622–631
2. Borges JB, Okamoto VN, Matos GF, Caramez MP, Arantes PR, Barros F, Souza CE, Victorino JA, Kacmarek RM, Barbas CS, Carvalho CR, Amato MB (2006) Reversibility of lung collapse and hypoxemia in early acute respiratory distress syndrome. Am J Respir Crit Care Med 174:268–278. doi:10.1164/rccm.200506-976OC
3. Hodgson CL, Tuxen DV, Davies AR, Bailey MJ, Higgins AM, Holland AE, Keating JL, Pilcher DV, Westbrook AJ, Cooper DJ, Nichol AD (2011) A randomised controlled trial of an open lung strategy with staircase recruitment, titrated PEEP and targeted low airway pressures in patients with acute respiratory distress syndrome. Crit Care 15:R133. doi:10.1186/cc10249
4. Lung Open Ventilation Study Investigators, Meade MO, Cook DJ, Guyatt GH, Slutsky AS, Arabi YM, Cooper DJ, Davies AR, Hand LE, Zhou Q, Thabane L, Austin P, Lapinsky S, Baxter A, Russell J, Skrobik Y, Ronco JJ, Stewart TE (2008) Ventilation strategy using low tidal volumes, recruitment maneuvers, and high positive end-expiratory pressure for acute lung injury and acute respiratory distress syndrome: a randomized controlled trial. JAMA 299:637–645. doi:10.1001/jama.299.6.637
5. Fan E, Wilcox ME, Brower RG, Stewart TE, Mehta S, Lapinsky SE, Meade MO, Ferguson ND (2008) Recruitment maneuvers for acute lung injury: a systematic review. Am J Respir Crit Care Med 178:1156–1163. doi:10.1164/rccm.200802-335OC
6. Gattinoni L, Caironi P, Cressoni M, Chiumello D, Ranieri VM, Quintel M, Russo S, Patroniti N, Cornejo R, Bugedo G (2006) Lung recruitment in patients with the acute respiratory distress syndrome. N Engl J Med 354:1775–1786. doi: 10.1056/NEJMoa052052
7. Grasso S, Mascia L, Del Turco M, Malacarne P, Giunta F, Brochard L, Slutsky AS, Marco Ranieri V (2002) Effects of recruiting maneuvers in patients with acute respiratory distress syndrome ventilated with protective ventilatory strategy. Anesthesiology 96:795–802
8. Constantin JM, Grasso S, Chanques G, Aufort S, Futier E, Sebbane M, Jung B, Gallix B, Bazin JE, Rouby JJ, Jaber S (2010) Lung morphology predicts response to recruitment maneuver in patients with acute respiratory distress syndrome. Crit Care Med 38:1108–1117. doi: 10.1097/CCM.0b013e3181d451ec
9. Muscedere JG, Mullen JB, Gan K, Slutsky AS (1994) Tidal ventilation at low airway pressures can augment lung injury. Am J Respir Crit Care Med 149:1327–1334. doi: 10.1164/ajrccm.149.5.8173774
10. Borges JB, Costa EL, Suarez-Sipmann F, Widström C, Larsson A, Amato M, Hedenstierna G (2014) Early inflammation mainly affects normally and poorly aerated lung in experimental ventilator-induced lung injury. Crit Care Med 42:e279–e287. doi: 10.1097/CCM.0000000000000161

11. Matthay MA (2014) Resolution of pulmonary edema. Thirty years of progress. Am J Respir Crit Care Med 189:1301–1308. doi: 10.1164/rccm.201403-0535OE
12. Constantin JM, Cayot-Constantin S, Roszyk L, Futier E, Sapin V, Dastugue B, Bazin JE, Rouby JJ (2007) Response to recruitment maneuver influences net alveolar fluid clearance in acute respiratory distress syndrome. Anesthesiology 106:944–951. doi: 10.1097/01.anes.0000265153.17062.64
13. Jabaudon M, Hamroun N, Roszyk L, Guérin R, Bazin JE, Sapin V, Pereira B, Constantin JM (2015) Effects of a recruitment maneuver on plasma levels of soluble RAGE in patients with diffuse acute respiratory distress syndrome: a prospective randomized crossover study. Intensive Care Med 41:846–855. doi: 10.1007/s00134-015-3726-0
14. Amato MB, Meade MO, Slutsky AS, Brochard L, Costa EL, Schoenfeld DA, Stewart TE, Briel M, Talmor D, Mercat A, Richard JC, Carvalho CR, Brower RG (2015) Driving pressure and survival in the acute respiratory distress syndrome. N Engl J Med 372:747–755. doi:10.1056/NEJMsa1410639
15. Steimback PW, Oliveira GP, Rzezinski AF, Silva PL, Garcia CS, Rangel G, Morales MM, Lapa E, Silva JR, Capelozzi VL, Pelosi P, Rocco PR (2009) Effects of frequency and inspiratory plateau pressure during recruitment manoeuvres on lung and distal organs in acute lung injury. Intensive Care Med 35:1120–1128. doi: 10.1007/s00134-009-1439-y
16. Silva PL, Moraes L, Santos RS, Samary C, Ornellas DS, Maron-Gutierrez T, Morales MM, Saddy F, Capelozzi VL, Pelosi P, Marini JJ, Gama de Abreu M, Rocco PR (2011) Impact of pressure profile and duration of recruitment maneuvers on morphofunctional and biochemical variables in experimental lung injury. Crit Care Med 39:1074–1081. doi: 10.1097/CCM.0b013e318206d69a
17. Guérin C, Reignier J, Richard JC, Beuret P, Gacouin A, Boulain T, Mercier E, Badet M, Mercat A, Baudin O, Clavel M, Chatellier D, Jaber S, Rosselli S, Mancebo J, Sirodot M, Hilbert G, Bengler C, Richecoeur J, Gainnier M, Bayle F, Bourdin G, Leray V, Girard R, Baboi L, Ayzac L, PROSEVA Study Group (2013) Prone positioning in severe acute respiratory distress syndrome. N Engl J Med 368:2159–2168. doi: 10.1056/NEJMoa1214103
18. Suzumura EA, Figueiró M, Normilio-Silva K, Laranjeira L, Oliveira C, Buehler AM, Bugano D, Passos Amato MB, Ribeiro Carvalho CR, Berwanger O, Cavalcanti AB (2014) Effects of alveolar recruitment maneuvers on clinical outcomes in patients with acute respiratory distress syndrome: a systematic review and meta-analysis. Intensive Care Med 40:1227–1240. doi: 10.1007/s00134-014-3413-6