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EDITORIAL

Assessment of oxygenation response to prone position ventilation in ARDS by lung ultrasonography

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Acute respiratory distress syndrome (ARDS) is of major concern for the intensivist, as ARDS can only be treated in the intensive care unit (ICU). A cornerstone treatment is mechanical ventilation in order to buy time while the disease leading to ARDS can be cured. Therefore, the first aim of mechanical ventilation is to maintain a viable gas exchange. Over the years we realized that the cost of mechanical ventilation, as measured by the occurrence of ventilator-induced lung injury (VILI) [1], was too high if the target of the mechanical ventilation was normal blood gases. From there, permissive hypercapnia and oxygen saturation between 85 and 90 % were accepted to decrease the risk of VILI.

To better tailor the ventilator settings, particularly to avoid potentially dangerous intratidal collapse and decollapse, increased attention was devoted to the characterization of the pathology underlying ARDS. To date, lung CT scan is the gold standard to assess the distribution of strain and from there to make inferences to minimize the occurrence of VILI. It should be mentioned, however, that no study demonstrated that patient outcome can be influenced from lung CT scan findings, essentially because no study has been done with this objective. Since ARDS lung characteristics cannot be monitored using CT imaging, methods feasible at the bedside are very attractive and lung ultrasound (US) is one of them [2]. One limitation of lung US is that the measurements do not quantify physical findings. Even though an aeration score has been developed, it is not quantitative as the Hounsfield units are for CT [3]. This US aeration score has been shown to correlate with PEEP-induced recruited lung volume obtained from the pressure–volume curve [4] and with weaning failure during spontaneous breathing trial [5]. Recently, however, it was shown that recruitment measured by CT scan (as re-inflation of previously not inflated regions) is not correlated with recruitment measured by the pressure–volume curve [6]. This last method and, by inference the US method, actually measure together both the aeration of previously non-aerated regions and a better inflation of lung regions already aerated. The regional hyperinflation, however, cannot be measured accurately either with CT (because of the mass increase of the ARDS lung) or lung US.

Haddam et al. [7] performed a multicenter study in 51 ARDS patients with the aim to predict the oxygenation response to the prone position session from using lung US aeration score. The patients included suffered equally from either primary or secondary lung injury and received appropriate lung-protective mechanical ventilation. The authors found that changes in PaO_2/F_IO_2 ratio and lung aeration score did not correlate in either early or late stage of prone position regardless of the focal or non-focal nature of ARDS. The same was true for changes in $PaCO_2$. For the oxygenation to increase, and for the $PaCO_2$ to decrease, from increased regional lung aeration the blood should continue to flow towards those reaerated lung areas.

Why did the increased aeration in the lung US score not correlate with the improvement in oxygenation, a result which is not surprising?

- The first reason is that not only ventilation but also perfusion is a critical determinant of oxygenation. The present results may indicate that in the subset of patients investigated by Haddam et al. [7] the pulmo-

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nary blood flow was diverted away the reaerated lung regions in the prone position. This is not in line with the fact that the pulmonary blood flow continues to prevail in the dorsal regions in the prone position, as observed in many animal studies [8].

- The second reason is that lung US aeration score does not measure reaeration accurately, although the lung US findings found by Haddam et al. [7] are qualitatively in line with the lung CT findings (increased aeration in dorsal lung regions associated with a decreased in aeration in ventral lung regions in the prone position).
- The third reason is that the aeration LUS score showing reaeration tracks hyperinflation and not only lung recruitment. At the very end, the present lung US findings are consistent with two previous CT studies [9, 10]. The change in oxygenation in the prone position did not correlate with either the static distribution of densities in the dorsal lung regions [10] or with lung recruitability in the supine position [9].
- The fourth reason is that the oxygenation response was not defined from predetermined criteria but retrospectively from the median value over the whole cohort. This method does not test the response to proning in a given patient.

In summary, the changes in aeration as seen by US or even more accurately quantitated by the CT scans cannot automatically predict the oxygenation response in every patient. The gas exchange in fact is only determined by the VA/Q ratio of the different regions, while at best the imaging techniques may only quantitate the degree of inflation, which is not equivalent to the degree of ventilation (part of the lung may be in fact hyperinflated and not ventilated, producing a different response for oxygen uptake and CO_2 clearance).

Is it important to predict oxygenation response to prone position ventilation? The response to this question is likely no. First, those trials that found benefits to patient outcome, either in meta-analysis [11] or in a single trial [12], included patients without taking into account oxygenation response to proning. Second, the main goal of mechanical ventilation in ARDS patients is to provide viable gas exchange, preventing, at the same time, excessive strain to the lung. Dramatic increase in oxygenation or PaO_2 higher than levels sufficient to provide an adequate oxygen transport to the tissues is not required during the ARDS treatment. In fact, in the ARMA trial those patients who were randomized to the higher tidal volume group had better oxygenation within the first week after randomization than those patients allocated to the lower tidal volume group but with a significantly worst outcome [13].

In conclusion, lung US allows monitoring of lung aeration at the bedside and the present results [7] are the expression of a negative control group: it was expected that lung US aeration score would not correlate with changes in gas exchange and this is what was found.

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Compliance with ethical standards

Conflicts of interest
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References

1. Slutsky A, Ranieri M (2013) Ventilator-induced lung injury. New Engl J Med 369:2126–2136
2. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ (2004) Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 100:9–15
3. Bouhemad B, Liu ZH, Arbelot C, Zhang M, Ferarri F, Le-Guen M, Girard M, Lu Q, Rouby JJ (2010) Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. Crit Care Med 38:84–92
4. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ (2011) Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med 183:341–347
5. Delgado Ayala LY, Torres O, Sanchez-Calzada A, Navarro JL, Torres A, Gastelum R, Romano Albornoz P, Arcos M, Monares EE, Aguirre J, Franco J (2015) Lung ultrasound to predict mechanical ventilation weaning failure. Intensive Care Med Exp 3:A317
6. Chiumello D, Marino A, Brioni M, Cigada I, Menga F, Colombo A, Crimella F, Algieri I, Cressoni M, Carlesso E, Gattinoni L (2016) Lung recruitment assessed by respiratory mechanics and computed tomography in patients with acute respiratory distress syndrome. What is the relationship? Am J Respir Crit Care Med 193:1254–1263
7. Haddam M, Zieleskiewicz L, Perbet S, Baldovini A, Guervilly C, Arbelot C, Noel A, Vigne C, Hammad E, Antonini F, Lehingue S, Peytel E, Lu Q, Bouhemad B, Golmard JL, Langeron O, Martin C, Muller L, Rouby JJ, Constantin JM, Papazian L, Leone M (2016) Lung ultrasonography for assessment of oxygenation response to prone position ventilation in ARDS. Intensive Care Med. doi:10.1007/s00134-016-4411-7
8. Glenny RW, Lamm WJ, Albert RK, Robertson HT (1991) Gravity is a minor determinant of pulmonary blood flow distribution. J Appl Physiol (1985) 71:620–629
9. Protti A, Chiumello D, Cressoni M, Carlesso E, Mietto C, Berto V, Lazzerini M, Quintel M, Gattinoni L (2009) Relationship between gas exchange response to prone position and lung recruitability during acute respiratory failure. Intensive Care Med 35:1011–1017
10. Papazian L, Paladini MH, Bregeon F, Thirion X, Durieux O, Gainnier M, Huiart L, Agostini S, Auffray JP (2002) Can the tomographic aspect characteristics of patients presenting with acute respiratory distress syndrome predict improvement in oxygenation-related response to the prone position? Anesthesiology 97:599–607
11. Gattinoni L, Carlesso E, Taccone P, Polli F, Guerin C, Mancebo J (2010) Prone positioning improves survival in severe ARDS: a pathophysiologic review and individual patient meta-analysis. Minerva Anestesiol 76:448–454

12. Guerin 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

13. ARDSnet (2000) Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. N Engl J Med 342:1301–1308