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REVIEW

Alveolar recruitment maneuvers in respiratory distress syndrome[☆]

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Abstract In patients with acute respiratory distress syndrome, heterogeneity in filling of the lung parenchyma results in collapsed or distended lung areas. Protective ventilation strategies based on the use of low volumes have been shown to increase survival in this context. For opening the lung, and in addition to PEEP, recruitment maneuvers are used–this practice remained the subject of debate.

The present review offers an update on the alveolar recruitment techniques, considering the great variability that exists in the application of these maneuvers, and the different factors that influence the response to maneuvering.

PALABRAS CLAVE
Síndrome de distrés respiratorio agudo;
Reclutamiento;
Ventilación mecánica

Maniobras de reclutamiento alveolar en el síndrome de distrés respiratorio agudo

Resumen En los pacientes con síndrome de distrés respiratorio agudo, la heterogeneidad en el llenado del parénquima pulmonar da lugar a que existan tanto áreas distendidas como colapsadas. Las estrategias de ventilación protectora basadas en el empleo de volúmenes bajos han mostrado en este contexto un aumento de supervivencia. Para abrir el pulmón, además de usar la PEEP, se emplean las maniobras de reclutamiento, todavía en debate.

En la presente revisión se analizan los fundamentos y técnicas para realizar reclutamiento alveolar, considerando la gran variabilidad que existe en cuanto a cómo aplicarlas y los distintos factores que influyen en la respuesta a las mismas.

Background

Acute respiratory distress syndrome (ARDS) remains an important cause of severe respiratory failure, with a mortality rate of up to 30–60% according to different studies.[1,2] It has been estimated that patients with ARDS represent up to 10–15% of all patients admitted to the Intensive Care Unit

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(ICU), and 20% of those who require mechanical ventilation during more than 24 h.[3]

The *babylung* concept refers to the great lung parenchyma heterogeneity that characterizes ARDS. Some lung regions are relatively well aerated and participate in gas exchange, while others are collapsed as a result of the inflammatory contents within the alveoli or because of the increase in interstitial pressure and the weight of the lung tissue. In this way, in the dependent pulmonary zones, with the patient in supine decubitus at dorsal level, aeration is poorer than in the non-dependent zones at sternal level. This results in very heterogeneous alveolar filling. Much of the research in relation to the treatment of ARDS has been designed to define protective ventilation strategies based on the use of low tidal volumes, which have been shown to improve patient survival.[4] However, such volumes can favor progressive alveolar collapse due to cyclic opening and closing, which further increases the lung damage. The application of positive end-expiratory pressure (PEEP) can stabilize the alveolus by avoiding the continuous repetition of parenchymal aperture and collapse. Based on the evidence in the literature, modifications in the prescribed mechanical ventilation parameters have been introduced over the years, with the use of lesser tidal volumes and higher PEEP levels.[5] While there is considerable agreement in calculating tidal volume, it is less clear which PEEP levels should be applied on an individual basis. A number of trials have been carried out analyzing the use of high or low PEEP in patients with ARDS—the results suggesting that high PEEP is associated with increased survival in such individuals.[6] On the other hand, however, excessive PEEP levels can worsen the damage by distending regions that are already open, giving rise to adverse hemodynamic effects.[7] In order to ''open the lung and keep it open'',[8] PEEP has been combined with alveolar recruitment (AR) maneuvers—the efficacy of which remains subject to debate.[9,10]

Definition and physiopathology

Alveolar recruitment is defined as the re-expansion of previously collapsed lung areas by means of a brief and controlled increase in transpulmonary pressure.[11] The idea of AR is to create and maintain a collapse-free situation with the purpose of increasing the end-expiration volume and improve gas exchange.

Since the 1970s, different experimental studies have investigated the relationship between alveolar volume and pressure and alveolar shape and size, and the ways in which volume changes affect alveolar structure.[12] In 1952, Day et al. applied different pressure levels to revert atelectasis in animal lungs. These authors found that low pressures are not effective even if maintained for prolonged periods of time, while high pressures are able to open the lungs but cause damage if maintained for a long time.[13] They concluded that a minimum pressure threshold must be exceeded in order to open an atelectatic lung, and that doing so safely requires precise control of the duration of application of such pressure.

Alveolar recruitment therefore has two fundamental components: the pressure level applied, and the time during which it is maintained.[14] The increase in transpulmonary pressure (transalveolar pressure would be a more accurate term) opens the terminal alveolar units according to their critical opening pressure, which varies greatly depending on their location. It has been seen that critical opening pressure is low in non-dependent regions, high in dependent regions, and intermediate in limiting territories.[15] Based on the ''open lung'' theory, it is considered that the entire lung mass could be reopened in the early stages of ARDS if sufficient transalveolar pressure is applied.[8] According to mathematical and experimental models, airway pressures of over 40 cmH_2O must be applied in order to achieve full recruitment.

In some studies, AR maneuvering has been made under radiological guidance using computed axial tomography (CAT). Gattinoni et al. studied the relationship between the percentage of potentially recruitable lung (as measured by CAT) and the clinical and physiological effects of different PEEP levels in 68 patients with ARDS.[16] They found that the percentage of potentially recruitable lung varies greatly from one patient to another, with an average of $13 \pm 11\%$, and that this parameter is related to PEEP response. As a result, it would be very useful to know the lung recruitment capacity before prescribing the ventilation parameters. Patients with greater recruitable tissue showed poorer oxygenation and compliance, a greater dead space, and increased mortality. However, it is not possible to determine the recruitment capacity of a given patient at the bedside. Costa et al. developed an impedance tomography-based algorithm for estimating recruitable alveolar collapse and hyperdistension, similar to that of CAT but without having to move the patient.[17] This algorithm allowed individualized PEEP titration. Other studies have analyzed the pressure–volume curve and especially its hysteresis as a predictor of lung recruitment capacity.[15,18] It has been seen that recruitment occurs along the entire pressure–volume curve, even above the upper inflexion point.[15] Hysteresis intrinsically reflects the recruited volume; as a result, increased curve hysteresis implies increased AR capacity.[18]

In relation to the use of complementary imaging techniques, Tomicic et al. distinguished between anatomical and functional recruitment.[19] Anatomical recruitment refers to the lung tissue in which collapse is reverted, and which can be evaluated by CAT. Functional recruitment in turn is related to improvement of intrapulmonary shunting. Aerating previously collapsed lung zones does not directly imply improved gas exchange, since during partial recruitment part of the perfusion of these alveolar units may be displaced toward other collapsed units, thereby countering both effects. Increased oxygenation will depend on the changes produced in the ventilation–perfusion ratio. Independently of the effect upon oxygenation, it is considered that AR, by increasing the aerated tissue, contributes to minimize the heterogeneity of the lung and avoid cyclic opening and closing. This in turn can prevent ventilator-associated lung injury.[20]

How alveolar recruitment is performed

The techniques used to perform AR and the results obtained vary greatly among the different studies, in terms of both