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EDITORIAL

Assessing lung recruitability: does it help with PEEP settings?

Luciano Gattinoni[1*], Francesca Collino[2] and Luigi Camporota[3]

Recruitment is a process expressing a transition from status A to status B. In acute respiratory distress syndrome (ARDS), status A (initial) is the level of inflation of the pulmonary units at end-expiration, while status B (final) is their level of inflation at end-inspiration following an increase in transpulmonary pressure. In the ARDS literature, under the term 'recruitment', two different conditions are included: (1) the regaining of aeration in atelectatic units at end-inspiration; (2) the recruitment of atelectatic and poorly aerated units to an overall better inflation status at end-inspiration.

Opening pressures

The recruitment is an inspiratory phenomenon which occurs continuously over a range of pressures from zero up to 50–60 cmH_2O. The pressure–recruitment relationship exhibits a sigmoidal shape like the pressure–volume curve [1]. Therefore, the distribution of opening pressures may be represented by a Gaussian curve, with a 'mode' of ~ 25–30 cmH_2O, and with only few units (2–5%) opening at pressures > 45 cmH_2O [2, 3]. Indeed, the pressure necessary to open an atelectatic pulmonary unit needs to overcome three forces [4]: (1) the superimposed pressure (~ 10–15 cmH_2O); (2) the surface forces (~ 15–20 cmH_2O)]; 3) the pressure needed to move the chest wall (~ 10–15 cmH_2O). These forces affect the opening threshold of an alveolus depending on the relative inflation status of neighboring alveoli within an isogravitational plane (i.e., crowding effect).

The kind of recruitment measured must be clearly specified as there is a substantial difference if we refer only to the reaeration of gasless atelectasis or if we include the greater inflation of poorly aerated alveoli (Fig. 1).

Recruitment maintenance

To keep the newly recruited units open, two conditions must be satisfied. First, the level of positive end-expiratory pressure (PEEP) should be sufficient to lift the chest wall and to overcome the compressive forces on the lung parenchyma [4]. Unfortunately, the PEEP required to maintain the recruitment of a fully open lung (opening pressure 45–60 cmH_2O) is in the order of 20–25 of cmH_2O [3]. Second, the tidal volumes should be adequate, as low tidal volumes, even in the presence of high PEEP, are likely to cause marked hypoventilation and reabsorption atelectasis overtime.

Interaction between opening pressure and positive end-expiratory pressure

From this perspective, it is evident that recruitment, as intended in clinical practice, depends on the relationship between the pressures needed to open alveolar units and that required to maintain recruitment. Therefore, the effects of recruitment will wane if PEEP levels are not set above the closing threshold pressure [3]. In this sense, the PEEP level should not be set based on the amount of potentially recruitable lung, but on the pressure needed to prevent the closing of newly opened alveolar units [5].

Available methods to assess recruitment

Gas exchange-based methods

These methods are widely used and rely on oxygenation, PEEP/FiO_2 tables or to the changes in oxygenation when decreasing alveolar pressure after a full inflation. However, these methods may be misleading, as oxygenation is deeply affected by hemodynamic changes (i.e., decreasing

*Correspondence: gattinoniluciano@gmail.com
[1] Department of Anesthesiology, University Medical Center Göttingen, Robert Koch Straße 40, 37075 Göttingen, Germany
Full author information is available at the end of the article

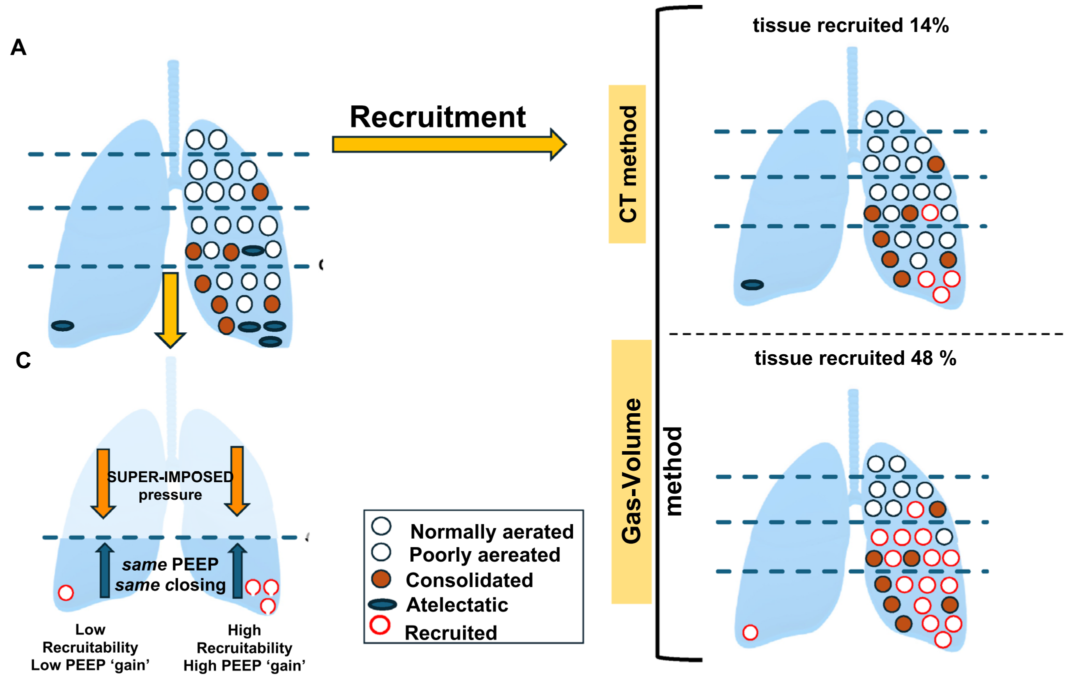

Fig. 1 Effect of recruitment as a function of the method used and effect of the PEEP applied. Panel **A**: In the right lung of the figures the different percentages (%) of pulmonary units in a typical ARDS patient are depicted (consolidated 24%, atelectatic 14%, poorly ventilated 34%, normally ventilated 28%). The left lung of the figure displays a single isolated atelectatic unit. (Panel **B**–upper) Using the percentages as in panel **A**, if the recruitment is assessed as reinflation of atelectatic unit (CT method) the resultant recruitment is 14%. (Panel **B**–lower) If the recruitment is assessed by the gas method, (which also includes increased aeration of poorly aerated units) the measured recruitment is of 48%. Panel **C**: The maintenance of recruitment is independent of the number of lung units recruited but depends on their physical characteristics such as closing pressures which are independent on the recruitability (intensive property of the system). Although the PEEP necessary to maintain the recruitment may be the same (independent of recruitment) the gain from the application of PEEP will be affected by recruitment and higher in the patients with higher potential for lung recruitment

of cardiac output independently to alveolar recruitment) [6].

CT-scan-based methods

These methods quantify the amount of lung recruitment, but their absolute value depends on the method used for the analysis. One method measures the difference between the non-aerated tissue before and after the increase in airway pressure (on average 12%, ranging from 0% to 35%) [7]; the second, measures the change in the anatomical distribution of aerated and non-aerated tissue, where the non-aerated tissue includes atelectatic and poorly aerated tissue [8]. Indeed, the first method provides values markedly lower than the values resulting from the second method.

Gas-volume-based methods

These methods define recruitment as the difference between the expected change in lung volume at a given pressure and the measured volume changed. If the latter is greater than expected based on the baseline compliance, "recruitment" is said to have occurred and is quantified accordingly. This method includes the dual pressure–volume curve and the recruitment-to-inflation ratio [9].

All these methods estimate the recruitment to a better inflation status of previously non-aerated and poorly aerated pulmonary units. The recruitment values are unrelated with ones measured by CT scan [10].

Other methods

The use of systems such as electric impedance tomography and ultrasound may give—through different physical principles—a quantitative or semi-quantitative estimation of the gas and tissue ratio of the lung before and after a recruitment pressure [11].

Clinical implications

The potential for lung recruitment, i.e., the absolute amount of atelectatic lung that can be inflated on inspiration, is generally considered the physiological basis for PEEP selection. In accordance with this concept, patients with greater recruitability would necessitate the application of higher PEEP levels.

However, as recognized by the recent guidelines from the European Society of Intensive Care Medicine [12], PEEP selection does not have precise rules, beyond the fact that PEEP levels > 15 cmH_2O in association with routinely performed recruitment maneuvers is associated with worst outcomes. Therefore, the assertion of an association between recruitability and PEEP levels is questionable from both physiological and physical perspectives. This is because the opening pressure and PEEP are 'intensive' properties of a physical system, meaning that its magnitude is independent on the size of the system. Consequently, the PEEP level is independent of the overall amount of potentially recruitable units and identical pressures are required to open and maintain the opening of one or a hundred pulmonary units [4]. In contrast, recruitability is an extensive property of the system and is proportional to the disease severity, lung size and lung weight. Therefore, the PEEP required to maintain open the recruited pulmonary units depends only on their physical characteristics, and not by the potential for lung recruitment. In addition, personalization cannot be limited to a single variable such as PEEP, but should involve several interconnected components such as inspiratory volumes, pressures, use of sighs, etc.

In conclusion, while recruitability gives important information on the severity of disease and the amount of atelectatic lung, PEEP selection requires an integrated assessment of other variables such as elastance and transpulmonary pressures and hemodynamics to be truly personalized. Attempts to PEEP selection only to recruitability may lead to confusion and potentially injurious ventilatory settings.

Author details

[1] Department of Anesthesiology, University Medical Center Göttingen, Robert Koch Straße 40, 37075 Göttingen, Germany. [2] Department of Surgical Sciences, University of Turin, Turin, Italy. [3] Department of Adult Critical Care, Centre for Human and Applied Physiological Sciences, Guy's and St. Thomas' NHS Foundation Trust, King's College London, London, UK.

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Conflict of interest

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