DO WE NEED TO PERFORM A SINGLE-STEP, MULTI-STEP, OR NO ALVEOLAR RECRUITMENT MANEUVER AT ALL?

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On one hand, postoperative pulmonary complications (PPCs) have been associated with increased early postoperative mortality, ICU readmission and length of hospital stay. On the other hand, general anesthesia disrupts the natural sigh reflex and contributes to alveolar collapse, significantly impairing oxygenation and gas exchange during surgery. Alveolar collapse or atelectasis affects nearly all patients under general anesthesia, leading to hypoxemia, postoperative pulmonary complications and prolonged recovery time (1-4). Thus, we must avoid PPCs throughout the perioperative phase (5-8). A lot of research has been done on the benefits of pulmonary-protective ventilation techniques, like positive end-expiratory pressure (PEEP) ventilation and low tidal volume ventilation, to lower PPCs (9). However, there is still disagreement and no set guidelines to abide by when it comes to the alveolar recruitment maneuver (RM). In order to open collapsed alveoli, a recruitment procedure involves a prolonged increase in airway pressure. Then sufficient PEEP is administered to maintain the alveoli open (10). RM aims to increase oxygenation and function as a component of a lung protection strategy. Through increased airway pressure, the RM can partially reverse pulmonary atelectasis and preserve the alveolar aperture. The clinical community is actively investigating the technique that optimally balances efficacy and safety, and this editorial assesses recent evidence for alveolar RM, integrating new findings and insights from key studies.

Recruitment maneuvers vary widely in their application, encompassing various approaches in terms of timing, pressure settings and repetition (4, 11-31). Based on the variation in airway pressure, we can separate RMs into stepwise (multistep) and persistent categories (single step). A stepwise increase in PEEP plus a gradual increase in tidal volume make up the stepwise RM (4). According to earlier systematic studies, RM enhances oxygenation and lowers PPCs in patients under general anesthesia (11). Nevertheless, the analysis only covered a small number of included papers and it did not differentiate between different types of surgery. A large multicenter randomized controlled study (RCT) found that the open-lung ventilation technique was not as good at lowering the incidence of PPCs as conventional protective ventilation (12). In order to address the impact of the RM on PPCs, respiratory mechanics and hemodynamics during surgery, Pei and coauthors conducted high-quality evidence of systematic review and meta-analysis of RCTs (13). The initial studies they found included 209 from PubMed, 532 from Web of Science, 421 from Embase, 926 from the Cochrane Library database and 81 from the Clinicaltrials.gov registry. These sources collectively yielded a total of 2,160 likely associated studies. Out of them, 1,087 were duplicate. After a careful analysis of the titles and abstracts of the remaining literature, 873 publications were deemed irrelevant and removed. After screening 200 full-text papers, only 17 of them met the criteria for inclusion. Ultimately, a total of 3,480 individuals from 17 RCTs were analyzed (13). PPCs with a general incidence of roughly 21.9% were observed (448/1734 in the non-RM group and 314/1746 in the RM group). With minimal variability, RMs dramatically decreased PPCs in comparison to the control group in obese and non-obese patients, as well. Only one study included participants who were over 65 years old. In individuals who were not elderly, RMs reduced the incidence of PPCs, but they had no effect on elderly patients. The results were tested for heterogeneity as well > 0.10; $I2 = 5\%$. Because there isn't enough research on the effects of RMs on the elderly, we should exercise caution when treating elderly patients (age ≥ 65) (13).

Another question to be raised is the use of one or repeated RMs. According to the evidence, one RM has a much higher incidence of lowering PPCs than repeated RMs. To be more precise, although repeated RMs also decreased the incidence of PPC, they were less effective than a single RM, and there was heterogeneity. The statistical analysis also shows a big difference in heterogeneity between the two methods (p for heterogeneity <0.05), which suggests that a single RM may work better than repeated RMs (14–30).
The data clearly shows that single RMs are effective in reducing PPCs, but the optimal timing for performing these maneuvers remains unclear. Although the literature highlights the advantages of both single and repeated RMs, it fails to offer definitive recommendations on the optimal timing of these maneuvers during the procedure.
For single RMs, it is still uncertain whether there is an ideal time point for maximum effectiveness. For repeated RMs, there is similarly no definitive answer regarding the frequency or timing of each maneuver that would offer the best outcomes. The available data lacks sufficient evidence to make firm recommendations on the precise timing or frequency of recruitment maneuvers in clinical practice.

Another ongoing debate is the sustained or stepwise RMs. Nine researchers applied sustained RMs, while eight applied stepwise RMs. The findings demonstrated that sustained RMs had a more notable impact on reducing the incidence of PPCs than stepwise RMs. With no evidence of heterogeneity in either grouping (14–30).
According to Rothen and colleagues, a recruited pressure of more than 40cm H_2O is necessary in order to guarantee opening in pulmonary atelectasis (31). There are investigations, which, based on the recruited pressure, are divided into two groups. While one used recruited pressure <40cm H_2O, other studies used pressure ≥ 40cm H_2O. The findings showed a decrease in the incidence of PPCs when the recruiting pressure was less than 40cm H2O. However, when the recruited

pressure was greater than 40cm H_2O, the results were not improved, and other issues could arise (14–31).

Recruitment, however, is not without its risks. The balance between adequate recruitment and the potential for barotrauma, volutrauma or hemodynamic instability, must be carefully managed by a multidisciplinary team. Notable is the hemodynamic stability throughout the RM. On the other hand, this does not mean that the RM has no effect on the circulatory system. The time at which each study recorded its data varied greatly; some studies reported their data 60 minutes after initiation, while others recorded their data prior to the conclusion of surgery. The right and left ventricular ejection fractions temporarily decrease during RMs as a result of the elevated transpulmonary pressure during RMs. This is actually due to increases in the central venous pressure, pulmonary vascular resistance index and pulmonary artery pressure. According to Celebi et al., the right ventricle was temporarily affected by the RM, and when the high airway pressure was released, the hemodynamics restored to normal (32). It was also shown in other studies that the right ventricular work increases only in the initial two minutes following intervention (33). Future research should concentrate on enhancing personalized strategies by considering patient-specific factors, including lung compliance, body habitus and pre-existing medical comorbidities and respiratory conditions.

RMs are frequently utilized in pediatric patients as well, to address conditions such as pulmonary atelectasis, particularly in critically ill or ventilated patients. In pediatric patients, recruitment maneuvers enhance lung function by reopening collapsed alveoli, thereby improving oxygenation and decreasing complications associated with ventilation. The application of respiratory techniques in pediatric populations necessitates meticulous oversight and personalized strategies, taking into account variables such as lung compliance, pre-existing disorders and hemodynamic stability. Research indicates that RMs effectively enhance respiratory outcomes in pediatric patients when applied correctly (34-38).
While standardized protocols provide a foundation, clinical judgment, combined with continuous monitoring and advanced imaging techniques, plays a critical role in optimizing outcomes. We expect ongoing trials and new studies to further refine these approaches, but until such data is available, careful clinical application and collaboration remain at the forefront of successful mechanical ventilation.

As we continue to learn and adapt, recruitment maneuvers will likely evolve, driven by innovations in ventilation technology and deeper insights into lung mechanics. For now, the focus should remain on multidisciplinary teamwork, rigorous patient monitoring and a personalized approach to each patient's ventilatory needs.
In conclusion, we must emphasize that the optimization of patients’ outcomes in contemporary anesthesiology depends on the integration of advanced techniques and the rigorous reassessment of traditional approaches. Alveolar RMs have emerged as a key intervention in mitigating

perioperative atelectasis. Despite their widespread adoption, the precise timing and frequency of alveolar RMs remain subjects of ongoing debate. This underscores the need for a more refined, evidence-based application of these maneuvers to enhance their efficacy and ensure superior clinical outcomes. Future research must focus on establishing standard protocols that tailor the use of alveolar RMs to individual patients' profiles, ultimately advancing the quality of perioperative care.

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