Alveolar recruitment maneuver and perioperative ventilatory support in obese patients undergoing abdominal surgery

**ABSTRACT**

The development of abdominal surgery represents an alternative therapy for the morbidly obese; however, patients undergoing this surgical procedure often experience postoperative pulmonary complications. The use of alveolar recruitment maneuvers and/or perioperative ventilatory strategies is a possible alternative to reduce these complications, focusing on the reduction of postoperative pulmonary complications. In this review, the benefits of perioperative ventilatory strategies and the implementation of alveolar recruitment maneuvers in obese patients undergoing abdominal surgery are described.

**Keywords:** Respiration, artificial; Obesity/surgery; Postoperative period; Postoperative complications; Pulmonary alveoli/physiopathology; Respiratory mechanics; Anesthesia

**INTRODUCTION**

Morbid obesity is considered an epidemic of global proportions. The origin of this problem is multifactorial and includes biological factors related to physical inactivity and to inadequate dietary patterns that are associated, in turn, with psychosocial factors related to the lifestyle adopted by the population. According to the Ministry of Health in Brazil, 15% of the population is obese; however, overweight individuals represent 48% of the population.

An alternative for the treatment of patients with morbid obesity is bariatric surgery. However, this procedure often results in postoperative pulmonary complications. The complications in the postoperative period are associated with a variety of factors, such as the supine position, muscle paralysis, and pneumoperitoneum, which results in reduced functional residual capacity (FRC) and increased volume of airway closure, thus causing atelectasis.

Perioperative pulmonary complications are significant causes of morbidity and mortality may persist for up to 2 weeks, and include the accumulation of carbon dioxide ($CO_2$), atelectasis, and bronchopulmonary infiltrates.

Some ventilatory strategies have been proposed and used to improve gas exchange during anesthesia and in the immediate bariatric surgery postoperative period. Among these strategies is the alveolar recruitment maneuver (ARM), which is used in mechanical ventilation (MV). In MV, the application of high levels of inspiratory pressure results in the expansion of collapsed alveoli to increase...
the arterial pressure of oxygen (PaO\(_2\)). This strategy aims to improve gas exchange, providing a more homogeneous ventilation of the lung parenchyma.\(^{(9,11)}\) The response after the use of ARM varies according to the nature, stage, and extent of pulmonary changes.\(^{(12)}\)

The ARM most commonly described in the literature is sustained inflation, with a rapid increase in pressure to 40 cmH\(_2\)O that is applied for a period of 60 seconds.\(^{(13)}\) Various types of recruitment maneuvers are described in the literature: (1) prolonged recruitment maneuvers with low pressure and increased positive end-expiratory pressure (PEEP) to 15 cm H\(_2\)O, associated with expiratory pauses of 7 seconds twice per minute for 15 minutes;\(^{(14)}\) (2) incremental increases in PEEP, limiting the maximum inspiratory pressure;\(^{(15)}\) and (3) ventilation with constant controlled pressure with PEEP staggering.\(^{(16)}\) However, regardless of the mechanism, the ARMs increase oxygenation, promoting improved ventilatory mechanics and the repair of damage to the lung epithelium.\(^{(17,18)}\)

Few studies have compared the use of ARM to ventilatory strategies aimed at alveolar derecruitment in obese patients undergoing abdominal surgery, which hampers evidence-based decision-making by clinicians. The objective of the present study was to present a literature review of the use of ARM and the perioperative ventilatory strategies aimed at derecruitment in obese patients undergoing abdominal surgery in obese patients. The articles selected are presented in Table 1. The sample size varied between 30 and 66 individuals of both genders, with a mean age ranging between 32 and 43 years old, who were undergoing abdominal surgery, perioperative ventilatory strategies, and alveolar recruitment maneuvers.

**DISCUSSION**

Obesity can impair lung function due to the effects on the respiratory mechanics, airway resistance, pulmonary volumes, and respiratory muscles, and obesity is recognized as an independent risk factor for postoperative pulmonary complications.\(^{(19)}\)

During general anesthesia and the immediate postoperative period, obese patients are more likely to develop postoperative pulmonary complications such as atelectasis and exhibit impaired pulmonary function compared to non-obese individuals.\(^{(20)}\) Therefore, the prevention of atelectasis is of utmost importance in this population because atelectasis affects respiratory mechanics, the volume of airway closure, and the oxygenation index (PaO\(_2\)/FiO\(_2\)).\(^{(20)}\)

Morbid obesity can promote a restrictive syndrome due to the accumulation of thoracic and abdominal fat, decreasing pulmonary volumes, expiratory reserve volume, and FRC due to reduced thorax wall movement, decreased pulmonary compliance, and increased airway resistance. Thus, anomalies in ventilation/perfusion appear, causing hypoxemia at rest and in the supine position, most likely due to the closure of small airways observed in this type of patient.\(^{(21)}\)

Considering these factors, different ventilatory strategies have been investigated to improve respiratory function in anesthetized obese patients. The ARM mechanism consists of sustained pulmonary inflations and the use of PEEP and has been suggested to improve oxygenation subsequent to anesthesia in obese patients.\(^{(21,22)}\)

In the study performed by Talab et al.,\(^{(20)}\) three different PEEP values (0, 5, and 10 cmH\(_2\)O) were evaluated after the ARM was performed (PEEP 40, maintained for 7-8 seconds) to determine which strategy was safer and more effective in preventing atelectasis in patients undergoing bariatric surgery. The results revealed that the patients in the group undergoing ARM and PEEP maintained at 10 cmH\(_2\)O after the maneuver exhibited a better oxygenation index in the
Table 1 - Clinical studies analyzing alveolar recruitment and perioperative ventilatory support

| Author                | Year | Sample (N) | Sample characteristic                                                                 | Objective                                                                 | Intervention                                                                 | Conclusion                                                                                                                                 |
|-----------------------|------|------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Ahmed et al.          | 2012 | G1 = 20    | Age between 20 and 50 years, BMI > 30kg/m², undergoing laparoscopic bariatric surgery | To determine the effects of single or repeated ARM followed by PEEP used to prevent atelectasis in the postoperative period | Group I: control group; Group II: ARM (30cmH₂O for 7 seconds) and posterior ventilation with PEEP of 10cmH₂O | Repeated ARM with posterior maintenance of PEEP of 10cmH₂O, PaO₂, PaCO₂, and static pulmonary compliance in obese patients undergoing bariatric surgery |
|                       |      | G2 = 20    |                                                                                       |                                                                           | Group III: ARM (30cmH₂O for 7 seconds, repeated every 30 minutes, repeating up to 90 minutes) and posterior ventilation with PEEP of 10cmH₂O | The ARM with PEEP of 30cmH₂O for 15 seconds, followed by the use of PEEP of 15cmH₂O improves pulmonary compliance and oxygenation in morbidly obese patients undergoing bariatric surgery. Furthermore, NIV after extubation was effective in maintaining oxygenation and preventing of alveolar derecruitment. |
|                       |      | G3 = 20    |                                                                                       |                                                                           | Group IV: ARM (30cmH₂O for 15 seconds) and PEEP of 15cmH₂O, NIV was used after extubation |                                                                           |                                                                                                                                            |
|                       |      | G1 = 20    |                                                                                       |                                                                           | Group II: ARM (30cmH₂O for 15 seconds) and PEEP of 15cmH₂O, NIV was used after extubation |                                                                           |                                                                                                                                            |
|                       |      | G2 = 20    |                                                                                       |                                                                           | Group III: ARM (30cmH₂O for 15 seconds) and PEEP of 15cmH₂O, NIV was used after extubation |                                                                           |                                                                                                                                            |
|                       |      | G3 = 20    |                                                                                       |                                                                           | Group IV: ARM (30cmH₂O for 15 seconds) and PEEP of 15cmH₂O, NIV was used after extubation |                                                                           |                                                                                                                                            |
|                       |      | G1 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G2 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G3 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G1 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G2 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G3 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G1 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G2 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G3 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G1 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G2 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |
|                       |      | G3 = 20    |                                                                                       |                                                                           |                                                                                                                             |                                                                                                                                            |

Continue...
| Author            | Year | Sample (N) | Sample characteristic | Objective                                                                 | Intervention                                                                 | Conclusion                                                                                       |
|-------------------|------|------------|-----------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Almarakbi et al.  | 2007| G1=10 patients | Patients between 18 and 60 years old, ASA grade II, BMI > 30kg/m², undergoing laparoscopic bariatric surgery | To test the hypothesis that ARM applied before extubation can improve pulmonary compliance | Group I: ventilation with PEEP of 10cmH₂O throughout surgical procedure; Group II: ARM (PEEP of 15cmH₂O for 15 seconds) and PEEP of 5cmH₂O throughout surgical procedure; Group III: ARM (PEEP of 15cmH₂O for 15 seconds) and PEEP of 10cmH₂O throughout surgical procedure; Group IV: ARM every 10 minutes (40cmH₂O for 15 seconds) followed by PEEP of 10cmH₂O throughout surgical procedure | The repeated use of ARM followed by PEEP of 10cmH₂O increased compliance, PaO₂, and decreased PaCO₂. Moreover, the beneficial effects on the oxygenation continued during the recovery period. |
| Cakmakkaya et al. | 2007| G1=10 patients | Obese patients undergoing open abdominal surgery | To evaluate the best intraoperative strategy for maintaining PaO₂ and static compliance | Group I: conventional ventilation with PEEP of 4cmH₂O throughout surgical procedure; Group II: ARM (PEEP of 40cmH₂O for 10 seconds) | The respiratory mechanics do not completely reverse the basal levels after deflation; however, the pulmonary compliance was completely restored using ARM. |
| Reinius et al.    | 2007| G1=10 patients | Patients with ASA grade II-III, BMI>40kg/m², aged between 25 and 54 years undergoing bariatric surgery | To assess the effect of general anesthesia in three different ventilation strategies in the reduction of atelectasis and improved respiratory function | Group I: conventional ventilation with PEEP of 10cmH₂O; Group II: ARM (PEEP of 5cmH₂O for 10 seconds) followed by zero PEEP; Group III: ARM (PEEP of 5cmH₂O for 10 seconds) followed by PEEP of 10cmH₂O | ARM followed by PEEP of 10cmH₂O reduces atelectasis and improves oxygenation in obese patients for a long period, whereas mechanical ventilation with PEEP of 10cmH₂O or ARM alone did not improve the respiratory function. |
| Souza et al.      | 2007| G1=14 patients | Patients diagnosed with grade III obesity undergoing bariatric surgery | To compare two techniques of ARM and assess its response through the PaO₂/PaO₂ relationship as well as the [PaO₂ + PaCO₂] sum in grade III obese patients | Group I: conventional ventilation with PEEP of 5cmH₂O; Group II: ARM with progressive increase of PEEP to 10, 15, and 20cmH₂O, for 40 seconds, and maintenance of each value of PEEP for 2 minutes; Group III: ARM with sudden increase of PEEP to 30cmH₂O for 40 seconds every 2 minutes | The technique of ARM with a sudden increase of PEEP to 30cmH₂O exhibited a better response in the PaO₂/PaO₂ relationship compared with the other groups. |
| Sprung et al.     | 2007| G1=9 patients | Morbidly obese patients (BMI>40kg/m²) undergoing open bariatric surgery | To investigate whether ARM reverses atelectasis in patients sedated with desflurane undergoing bariatric surgery | Group I: ventilation with PEEP of 4cmH₂O; Group II: starts ventilation with PEEP of 4cmH₂O, after 3 breaths, PEEP of 10cmH₂O, 3 breaths PEEP of 15cmH₂O and 20cmH₂O maintained for 10 respiratory cycles | Use of increasing amounts of PEEP is an effective method to improve oxygenation in patients undergoing bariatric surgery. |
| Talb et al.       | 2007| G1=22 patients | Obese patient with BMI between 30 and 50kg/m², aged between 20 and 50 years, undergoing laparoscopic bariatric surgery | To assess the safety and effectiveness of ARM according to the different PEEP used in the postoperative of bariatric surgery to prevent pulmonary atelectasis | Group I: ARM (PEEP 40, for 7-8 seconds) and ventilated with PEEP 0; Group II: ARM (PEEP 40, for 7-8 seconds) and ventilated with PEEP 5cmH₂O; Group III: ARM (PEEP 40, for 7-8 seconds) and ventilated with PEEP 10cmH₂O | ARM followed by ventilation with PEEP of 10cmH₂O is effective in preventing atelectasis and is associated with better oxygenation, shorter stay in the recovery room, and decreased postoperative pulmonary complications in obese patients undergoing bariatric surgery. |
| Chahoub et al.    | 2007| G1=26 patients | Morbidly obese patients (BMI>40kg/m²) undergoing open bariatric surgery | To assess the effect of ARM followed by different values of PEEP on PaO₂ values in morbidly obese patients undergoing bariatric surgery | Group I: conventional ventilation with PEEP of 8cmH₂O; Group II: ARM (PEEP of 40cmH₂O for 15 seconds) followed by ventilation with PEEP of 8cmH₂O | The addition of ARM followed by ventilation with PEEP of 8cmH₂O improves PaO₂ in the intraoperative period in morbidly obese patients undergoing the open bariatric surgery. |
Intraoperative and postoperative periods, as well as a decreased incidence of pulmonary atelectasis and minor complications compared to the other groups. However, the study by Reinius et al. (22) analyzed the effects of three different ventilation strategies in anesthetized patients undergoing bariatric surgery to determine which strategy was most effective in reducing atelectasis. The patients were divided into a conventional ventilation group (PEEP 10cmH\textsubscript{2}O) and groups of individuals undergoing ARM (PEEP 55cmH\textsubscript{2}O for 10 seconds) followed by zero PEEP (ZEEP) or PEEP of 10cmH\textsubscript{2}O. Corroborating the findings of Talab et al., (20) it was observed that ARM followed by PEEP of 10cmH\textsubscript{2}O reduced atelectasis and improved oxygenation in obese patients, thus indicating that the maintenance of optimal PEEP after the maneuver improves its benefits.

When comparing patients that used ARM with those who did not, with both groups being ventilated with PEEP of 8cmH\textsubscript{2}O during the surgical procedure, it was observed that the addition of ARM followed by ventilation with PEEP of 8cmH\textsubscript{2}O improved PaO\textsubscript{2} in the intraoperative period in morbidly obese patients during open bariatric surgery. (23) However, when the goal is to improve PaO\textsubscript{2} and pulmonary compliance during surgery and throughout the postoperative period, Almarakbi et al. (24) demonstrated that ARM repeated every 10 minutes (40cmH\textsubscript{2}O for 15 seconds) followed by PEEP of 10cmH\textsubscript{2}O throughout the surgical procedure resulted in increased compliance, increased PaO\textsubscript{2}, and the reduction of PaCO\textsubscript{2}. Moreover, the beneficial oxygenation effects persisted during the recovery period.

Another important factor related to ARM is its gradual or sudden application. This relationship was explored in the study by Souza et al., (25) which demonstrated that the technique of ARM with sudden increases in PEEP to 30cmH\textsubscript{2}O resulted in the best response in the PaO\textsubscript{2}/FiO\textsubscript{2} relationship compared to the gradual increase of PEEP. However, Futier et al. compared a ventilatory strategy associated with the use of ARM in healthy and obese subjects undergoing abdominal surgery. Patients in both groups were intubated and ventilated with 8mL/kg controlled volume and PEEP equal to zero. The ventilation protocol used 0.5% FiO\textsubscript{2}. Pneumoperitoneum was induced, and the reduction of PaCO\textsubscript{2} was maintained at 12cmH\textsubscript{2}O until the end of the surgical procedure. The authors demonstrated that this ventilation option is tolerated by patients undergoing abdominal surgery. Moreover, this approach results in improved arterial oxygenation. Corroborating this finding, Hemmes et al. compared conventional ventilation with PEEP of 2cmH\textsubscript{2}O to a group treated with the following: initial PEEP of 10cmH\textsubscript{2}O, PEEP raised in intervals of 4cmH\textsubscript{2}O to 30cmH\textsubscript{2}O and then maintained for three breath cycles, and return to PEEP of 10cmH\textsubscript{2}O. The authors reported improvements in respiratory function and oxygenation in both groups, indicating that the use of such protocols can avoid the deleterious effects of pneumoperitoneum. (26)

The use of ARM during and/or after bariatric surgery has been shown to be beneficial in several studies. The maintenance of its effects depends on repetition; thus, increasing the frequency of the maneuver is necessary. Based on this fact, Ahmed et al. aimed to evaluate the effect of ARM repetition with respect to oxygenation and the reduction of atelectasis. To do so, 60 patients were randomly allocated into three groups: conventional ventilation, single ARM (40cmH\textsubscript{2}O for 7 seconds), and ARM repeated every 30 minutes. All groups were treated with PEEP set at 10cmH\textsubscript{2}O. In addition to improving gas exchange and respiratory mechanics, repeated ARM maintained its beneficial effects during the postoperative period. (27)

The optimization of PEEP may be an important factor during the perioperative period. This is clear in the study by Weingarten et al., (28) which tested the hypothesis that the optimization of PEEP improves oxygenation in patients over 65 years old undergoing abdominal laparoscopic surgery. These researchers compared a group that performed this strategy to a control group that received conventional ventilation. A tidal volume of 10mL/kg and PEEP ventilation was applied in the control group. A tidal volume of 6mL/kg and PEEP of 4cmH\textsubscript{2}O was applied in the group undergoing this strategy, with PEEP adjusted in three steps: PEEP was raised from 4cmH\textsubscript{2}O to 10cmH\textsubscript{2}O for three breath cycles, followed by three cycles of 15cmH\textsubscript{2}O and then ten cycles with PEEP of 20cmH\textsubscript{2}O. After performing this maneuver, PEEP was maintained at 12cmH\textsubscript{2}O until the end of the surgical procedure. The authors demonstrated that this ventilation option is tolerated by patients undergoing abdominal surgery. Moreover, this approach results in improved arterial oxygenation. Corroborating this finding, Weingarten et al. compared conventional ventilation with PEEP of 2cmH\textsubscript{2}O to a group treated with the following: initial PEEP of 10cmH\textsubscript{2}O, PEEP raised in intervals of 4cmH\textsubscript{2}O to 30cmH\textsubscript{2}O and then maintained for three breath cycles, and return to PEEP of 10cmH\textsubscript{2}O. The authors reported an improvement in oxygenation and respiratory mechanics in the short term in these patients. (29)
The application of ARM during surgery can result in short-term effects. Testing this hypothesis, Ahmed et al., conducted a study with three groups of obese patients undergoing bariatric surgery, comparing a conventionally ventilated group with a group receiving ARM with PEEP of 40cmH\(_2\)O and a third group receiving the same maneuver repeated 30 and 90 minutes after surgery; both of the ARM groups used PEEP of 10cmH\(_2\)O until the end of the procedure. The authors demonstrated that ARM improved gas exchange; however, the repetition maintained adequate gas exchange and also resulted in better compliance.\(^{(27)}\)

One of the factors that may be related to a reduction of the ARM effect is pulmonary derecruitment. The studies by Futier et al.\(^{(30)}\) and El-Sayed et al.\(^{(31)}\) aimed to determine whether the use of noninvasive ventilation (NIV) after extubation in obese patients who had received ARM would be effective in oxygenation maintenance. Both studies reported that the use of NIV after extubation in this patient population improved oxygenation and pulmonary compliance and prevented alveolar derecruitment. Another possible alternative to modify the outcomes after extubation would be to perform ARM before extubation. It was with this objective that Cakmakkaya et al. tested the hypothesis that the application of ARM before extubation could improve pulmonary compliance. ARM was used with PEEP of 40cmH\(_2\)O for 10 seconds in patients undergoing open abdominal surgery. The authors demonstrated that there was an improvement in the pulmonary compliance of these patients.\(^{(32)}\)

Clinically, the studies demonstrate that perioperative ventilatory strategies and ARM are good alternatives in improving ventilatory mechanics and gas exchange in obese patients. However, these studies demonstrated the need for adequate PEEP after the use of these ventilation strategies. Most studies demonstrated that PEEP of 10cmH\(_2\)O is a good alternative for maintaining the effects achieved with the ARM and that the use of non-invasive ventilation may be an alternative after extubation for such patients.

The studies presented in this review suggest that ARM is an effective technique when performed to prevent pulmonary complications in obese patients undergoing abdominal surgery. ARM is associated with better oxygenation and respiratory mechanics and a reduction in pulmonary complications in the postoperative period in obese patients undergoing bariatric surgery. However, recent studies are highly heterogeneous, which hinders the analysis of the results and the performance of meta-analysis. The absence of randomized and controlled trials with adequate sample sizes increases the risk of bias, such as allocation concealment, bias of detection, attrition, and selection of results, thereby limiting the results presented here. Furthermore, using the studies included in this review, it is not possible to analyze clinical outcomes such as the length of stay or mortality. In addition, some factors related to ARM remain to be further elucidating, including (1) the PEEP values used, (2) the optimal PEEP after ARM, (3) the timing of ARM to avoid derecruitment, (4) the target number of repetitions of ARM, and (5) the safety of the maneuver with respect to clinical outcomes.

**FINAL CONSIDERATIONS**

Several studies have addressed the effect of alveolar recruitment maneuver and ventilatory strategies that aim to prevent derecruitment during anesthetic procedures in obese patients undergoing abdominal surgery. The alveolar recruitment maneuver seems to be a viable strategy for the prevention of pulmonary complications such as atelectasis and the improvement of gas exchange and respiratory mechanics.
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