Review Article

Intraoperative protective lung ventilation strategies in patients with morbid obesity

ABSTRACT

Postoperative pulmonary complications (PPCs) occur frequently and are associated with a prolonged hospital stay, increased mortality, and high costs. Patients with morbid obesity are at higher risk of perioperative complications, in particular associated with those related to respiratory function. One of the most prominent concerns of the anesthesiologists while taking care of the patient with obesity in the perioperative setting should be the status of the lung and delivery of mechanical ventilation as its strategy affects clinical outcomes. Negative effects of mechanical ventilation on the respiratory system known as ventilator-induced lung injury include barotrauma, volutrauma, and atelectrauma. However, the optimal regimen of mechanical ventilation still remains a matter of debate. While low tidal volume (VT) strategy has become a widely accepted standard of care, the protective role of PEEP and recruitment maneuvers is less clear. This review focuses on the pathophysiology of respiratory function in patients with morbid obesity, the effects of mechanical ventilation on the lungs, and optimal intraoperative strategy based on the current state of knowledge.

Key words: Driving pressure, intraoperative care, obesity, positive end-expiratory pressure, protective mechanical ventilation, recruitment maneuver

Mechanical ventilation is a cornerstone of the intraoperative management of the surgical patient and is mandatory in most surgical procedures. Postoperative pulmonary complications (PPCs) have a negative impact on patients' outcomes, increasing surgery-associated mortality and hospital length of stay. Obesity, especially when combined with certain surgical techniques such as pneumoperitoneum or steep Trendelenburg position, poses specific challenges for anesthesiologists. Providing mechanical ventilation to severely obese patients during surgery can involve technically complex challenges, including maintaining a patent airway, properly ventilating the lungs, and successfully liberating the patient from the ventilator. In this review, we are going to discuss lung-protective ventilatory strategies in surgical patients with morbid obesity.

Access this article online	
Website: www.saudija.org	Quick Response Code
DOI: 10.4103/sja.sja_386_22	

Physiological Changes of the Respiratory System in Patients with Morbid Obesity

Obesity poses major stress upon the respiratory system in the form of thoracic and abdominal fat which induces multiple functional changes, including decreased vital capacity, inspiratory capacity, expiratory reserve volume, and functional residual capacity (FRC) which leads to the formation of atelectasis, and changes in lung and chest wall mechanics.[1,2]

How to cite this article: Balonov K. Intraoperative protective lung ventilation strategies in patients with morbid obesity. Saudi J Anaesth 2022;16:327-31.

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Submitted: 13-May-2022, **Accepted:** 14-May-2022, **Published:** 20-Jun-2022

These changes as well as the higher intra-abdominal pressure explain the high occurrence of gas exchange impairment, respiratory mechanics alterations, and hemodynamic compromise.[3] In addition, closing capacity in individuals with obesity is close to or may fall within tidal breathing, particularly in the supine or recumbent position.[4] Breathing at low volumes increases airway resistance with expiratory flow limitation and gas trapping owing to early airway closure and subsequent generation of auto-positive end-expiratory pressure (PEEP). The presence of auto-PEEP increases the work of breathing, which is already elevated because of reduced compliance. Above changes in lung mechanics impair the capacity of patients with obesity to tolerate apneic episodes with early-onset oxygen desaturation. At baseline, ventilation-perfusion mismatch is present in the obese, with preserved perfusion to the bases and diminished ventilation to those areas from atelectasis. Exercise capacity is reduced in obesity because of increased work of breathing and cardiovascular compromise. The changes in lung function, including auto-PEEP, are more severe when the patient moves from the upright to the supine posture.[5,6]

A special condition causing many significant changes in the respiratory system is central obesity. Even during spontaneous breathing, individuals with central obesity have reduced lung volumes and FRC. The massive load of the obese abdomen and the distribution of adipose tissue in the thoracic region reduce lung volume and impair the stability of the airways. The mass of the abdomen against the diaphragm also hinders the normal range of diaphragmatic excursion which leads to the development of atelectasis during spontaneous breathing.[2,7]

Physiological Changes of the Respiratory System during Mechanical Ventilation

Mechanical ventilation can be harmful even in healthy lungs, triggering pathophysiological mechanisms leading to ventilator-induced lung injury (VILI). The main determinants of VILI include high pressures (barotrauma), high tidal volumes (VT) (volutrauma), and cyclic opening and closing of respiratory units (atelectrauma). All of these features damage the epithelial and endothelial components of the alveolo-capillary membrane which triggers the release of pro-inflammatory cytokines and the formation of pulmonary edema which further worsens the injury.[8,9]

During anesthesia and mechanical ventilation, atelectasis can develop into a significant problem for patients with obesity. Soon after induction of anesthesia, the FRC, which is a reserve of oxygen, decreases by an average of 500 ml in adults; added to the volume lost by going from the upright to the supine position, FRC is reduced from approximately 3,000 ml to just more than 2,000 ml, i.e., close to residual volume. The major contributing factors to this drop are paralysis, general anesthesia, and supine positioning.[10] The decrease in respiratory muscle tone due to muscle paralysis causes cranial displacement of the diaphragm which decreases FRC even further and contributes to atelectasis formation, especially in patients with obesity. Also, during paralysis, abdominal pressure is transmitted mostly to the gravity-dependent region of the lung, and the non-dependent regions of the lungs are preferentially ventilated, leading to ventilation-perfusion mismatch. This occurs even with applied high levels of PEEP. Prevention of atelectasis both during anesthesia and in the postoperative period is important for the integrity of the lung. Atelectasis impairs gas exchange and increases physiological shunt, ventilation-perfusion mismatch, and work of breathing. One of the options to counteract the effect of obesity on lung function is to apply PEEP.[11] However, it has been shown that PEEP levels up to 15 cm H2O cannot prevent the decline of FRC caused by increased intra-abdominal pressure, and are actually associated with reduced oxygen delivery as a consequence of reduced cardiac output.[12] To evaluate the role of PEEP in the prevention of PPCs in patients with morbid obesity, the multicenter international PRotective ventilation with Higher versus Lower PEEP during General Anesthesia for Surgery in OBESE patients (PROBESE) trial was conducted.[13] Two ventilation strategies in patients undergoing major surgeries were compared - low PEEP (4 cm H_2O) and high PEEP (12 cm H_2O) combined with recruitment maneuvers. In both groups, a low VT strategy was used. No difference in the incidence of PPC was found between the two groups. PROBESE as well as two other major trials, The PROtective Ventilation using HIgh versus LOw positive end-expiratory pressure and Individualized perioperative open-lung approach versus standard protective ventilation in abdominal surgery,[14,15] have been included in a recently published meta-analysis[16] that compared 1913 patients in the high-PEEP group to 1924 patients in the low-PEEP group. No benefits of prophylactic use of high PEEP levels on the incidence of PPCs have been demonstrated. However, less hemodynamic impairment was observed in the low-PEEP arm. Given the data from the recent studies, it appears that a strategy allowing partial lung collapse and less strain may be beneficial on VILI to higher PEEP, which is required to keep the lungs open but at the same time causes an increased strain.

Mechanical ventilation with a high fraction of inspired oxygen (FiO_2) may add to lung collapse (absorption atelectasis) by substituting alveolar nitrogen with oxygen.

Compared to ventilation with 100% oxygen, using lower FiO_2 ventilation with 80% O_2 may decrease the degree of absorption atelectasis.[10,11] The combination of a decreased FiO_2 and PEEP during awakening from general anesthesia, may limit the degree of atelectasis and the incidence and duration of hypoxemia in the postoperative period.

Mechanical Ventilation of the Surgical Patient with Obesity

While anesthesia and mechanical ventilation have become very safe practices, the contribution of PPC to surgical mortality and morbidity remains fairly high.[17] The studies showing that VILI can occur in healthy patients gave a strong drive to the research of lung-protective mechanical ventilation techniques in the operating room, deriving concepts from the advances achieved in the intensive care unit (ICU), where the reduction of Vt in acute respiratory distress syndrome (ARDS) patients lead to a decreased mortality.[18,19]

There has been debate about which ventilator setting is the best to use in patients with obesity. Several studies compared the volume-controlled mode of ventilation (VCV) to the pressure-controlled mode (PCV) without showing clinically relevant differences. Dual-controlled ventilation modes have lately gained a lot of popularity, mostly due to their universal applicability. They are available under different brand names and they combine the best of two worlds - it is a pressure-controlled mode with the decelerating inspiratory flow that adjusts the inspiratory pressure within the safe limits to achieve a target value of the Vt. The ability of these modes to maintain guaranteed minute ventilation while avoiding elevated peak pressures in settings of sometimes rapidly changing pulmonary and chest wall compliances during the surgery explains their wide acceptance among the anesthesiologists.

One of the first trials that demonstrated the beneficial effect of intraoperative protective lung ventilation was published in 2013.[20] Two years later, a meta-analysis published on more than 2000 patients included in 15 randomized controlled trials (RCTs) observed a dose-response relationship between Vt and the development of PPCs: the lower the Vt, the lower the incidence of PPCs.[21] Also, experimental studies showed that protective mechanical ventilation with lower Vt, lower driving pressure (ΔP), and low to moderate PEEP may protect the lung during surgery from activation of the inflammatory response, and minimize lesions of the alveolar-capillary barrier.[22,23]

Protection against VILI includes avoidance of high pressure leading to barotrauma, high Vt leading to volutrauma, and cycling reopening and closing of alveolar units leading to atelectrauma. First, the use of low VT (6–8 mL/kg of ideal body weight) should be used in patients with obesity, as it was found to be associated with a reduction in the risk of PPCs.[20] Second, the reduction in ΔP defined as the difference between the plateau pressure (Pplat) and PEEP, should be minimized with the reduction in Vt. Ideally, in patients with obesity, a ΔP less than 16 cm H_2O should be maintained. This may be a challenge in the settings of pneumoperitoneum, Trendelenburg position, or a combination of both. The optimization of PEEP has been a matter of debate for many years.[24] Physiologic trials showed that the application of higher 10–12 cm H_2O levels of PEEP during surgery can keep the lung fully open. However, beneficial effects were immediately lost just after extubation. Using low to moderate PEEP levels up to a maximum of 10 cm H_2O was not associated with increased ΔP. Moreover, it was shown that a PEEP increase can even be detrimental, if it is associated with the worsening of lung compliance, despite the benefit of gas exchange.[25] In conclusion, based on the current evidence, the routine use of higher PEEP levels cannot be recommended as a standard-setting in all patients with obesity, and low-moderate levels should be employed.

A recruitment maneuver (RM) is the temporary application of an end-expiratory pressure that is significantly greater than pleural pressure. They are aimed at restoring lung aeration through the increase of transpulmonary pressure and are often suggested in conjunction with higher PEEP levels. The ΔP is typically delivered over several seconds. The applied pressure gradient needs to be high enough to expand collapsed alveoli that have opening pressures higher than the normal ventilating peak pressures. These maneuvers can be considered a rescue maneuver to overcome an intraoperative oxygenation impairment or can be routinely performed as a preventive measure. It is the peak end-inspiratory pressure, not the PEEP, that recruits atelectatic alveoli. The two major variables to consider when performing RMs are the level of pressure applied and the time over which such pressure is applied.[26] There are different methods to perform RM intraoperatively, including manual squeezing of the anesthesia balloon or stepwise changes in Vt and/or inspiratory pressure. A commonly used method is the "bag-squeezing" maneuver, which results in the delivery of higher airway pressure, with the ventilator switched to manual mode and the adjustable pressure limiting valve set to 30–40 cm H_2O. This technique has several serious limitations, in particular the inaccuracy of the manual squeezing in maintaining a fixed pressure and the loss of pressure immediately after the maneuver which often results in de-recruiting the lungs.[27] A ventilator-based cycling maneuver is performed progressively by increasing VT until a Pplat of 30–40 cm H_2O is reached, maintaining

Pplat at this level for 3–4 respiratory cycles followed by decreasing the Vt to the desired target while titrating PEEP to achieve the best compliance of the respiratory system. There is not sufficient evidence to recommend the routine preventative use of RM. If the clinician opts for the use of RM, there is a strong pathophysiological rationale suggesting that ventilator-based maneuvers should be preferred to the conventional bag-squeezing. RMs should not be performed unless patients are hemodynamically stable and euvolemic, because these maneuvers may lead to a significant decrease in preload and hypotension.

Monitoring of the Mechanically Ventilated Patient with Obesity

In general, monitoring a patient with obesity is no different than monitoring other patients who are mechanically ventilated. All patients should have Vt between 6 and 8 mL/kg ideal body weight. The Pplat is measured by extending the time at inspiration for lung pressure to equilibrate at that volume. The magnitude of Pplat depends on the respiratory system, lung, and chest wall compliance, as well as Vt, and represents the elastic recoil pressure of the lung. A Pplat of 28–30 cm H_2O is considered acceptable in most patients with obesity. The ΔP that is measured as a difference between Pplat and PEEP reflects the compliance of the respiratory system, which is itself related to the end-expiratory volume of healthy lungs. Recently, intraoperative ΔP above 13 cm H_2O was associated with a two-fold increase in the incidence of PPCs.[23] Keeping the ΔP below a desired threshold is not always easy, as a patient might be difficult to ventilate for the modifications occurring during the surgical procedure. However, the goal should be to keep the ΔP as low as possible, and the increase in PEEP should not lead to an increase in the ΔP. ΔP less than 16 cm H_2O should be a good goal for a patient with obesity. Thus, all of these variables should be monitored with every patient/ventilator assessment. In addition, auto-PEEP, compliance, and airways resistance should be monitored regularly with the frequency dependent on the patient's overall condition. Auto-PEEP can be monitored using the ventilator's automated system, as in other patients suspected of having auto-PEEP.[11]

Summary

- Patients with obesity undergoing anesthesia and surgery are at risk of developing atelectasis, expiratory flow limitation, auto-PEEP, increased work of breathing, and decreased oxygenation. During the perioperative period, attention must be paid to avoiding these complications.
- Protective intraoperative ventilation should comprise a low Vt of 6–8 mL/kg of ideal body weight, the lowest possible ΔP, ideally below 16 cm H_2O, and moderate-low PEEP levels except for laparoscopy and long surgical procedures that might benefit from a slightly higher PEEP.
- To prevent absorption atelectasis and oxygen toxicity, FiO_2 should be limited to the level required to maintain adequate oxygen saturation (SpO2 >92%), ideally between 0.5 and 0.8.
- Recruitment maneuvers should be used judiciously in selected patients to improve oxygenation. The ventilator-based technique should substitute the conventional bag-squeezing.
- When possible, the head of the bed should be maintained in at least a 30° head-up position.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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