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Perioperative ventilatory strategies in cardiac surgery

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Recent data promote the utilization of prophylactic protective ventilation even in patients without acute respiratory distress syndrome (ARDS), and especially after cardiac surgery. The implementation of specific perioperative ventilatory strategies in patients undergoing cardiac surgery can improve both respiratory and extra-pulmonary outcomes. Protective ventilation is not limited to tidal volume reduction. The major components of ventilatory management include assist-controlled mechanical ventilation with low tidal volumes (6–8 mL kg^{-1} of predicted body weight) associated with higher positive end-expiratory pressure (PEEP), limitation of fraction of inspired oxygen (FiO_2), ventilation maintenance during cardiopulmonary bypass, and finally recruitment maneuvers. In order for such strategies to be fully effective, they should be integrated into a multimodal approach beginning from the induction and continuing over the postoperative period.

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Introduction

Despite its beneficial technological advances, cardiac surgery with or without extracorporeal circulation (ECC) still causes substantial respiratory morbidity, leading to prolonged intensive care and hospital length of stay [1]. Several mechanisms are potentially involved and include ischemia–reperfusion phenomena, ventilation disorders or overload-related lung injury due to transfusion or early respiratory mechanics impairment [1–4]. Systemic inflammation due to ECC and aggressive high tidal volume ventilation can cause non-cardiogenic pulmonary edema or other organ failure [5–7]. Perioperative pulmonary morbidity related to these dysfunctions may manifest itself in different ways, from simple atelectasis to acute respiratory distress syndrome (ARDS) [1,2]. To be effectively contained, ischemia–reperfusion lesions necessitate no disruption in pulmonary artery blood flow, which can be achieved with specific ECC methods but further complicates the proceedings [3,4]. Conversely, adequate ventilatory strategies could prevent various lung injuries, such as atelectasis, which lead to intra-pulmonary shunt and are the leading cause of postoperative hypoxemia [5]. The implementation of protective perioperative ventilation especially with reduced tidal volumes and fraction of inspired oxygen (FiO_2) as well as increased respiratory rate and positive end-expiratory pressure (PEEP) levels may improve patients' outcomes following cardiac surgery with cardiopulmonary bypass [6–12].

A brief history of mechanical ventilation in the operating room: from high volumes and zero end-expiratory pressure to low volume with positive end-expiratory pressure

The main objectives of mechanical ventilation during cardiac surgery, outside the bypass period, are to ensure adequate oxygenation along with adequate carbon dioxide removal and to avoid postoperative pulmonary complications. Although apparently straightforward, these goals (oxygenation and CO_2 removal) are based on principles described in the early 1960s by Bendixen et al. [13] who showed that the use of high tidal volume ventilation during surgery led to the prevention of atelectasis and respiratory acidosis and also reduction of per-operative desaturation. This concept markedly influenced perioperative ventilatory management and this work is still cited in recent reference books [14] but is now questionned. It should be noted that data on perioperative atelectasis presented by Bendixen et al. [13] were obtained with zero end-expiratory pressure (ZEEP) and with high FiO_2 levels. At that time, some publications even suggested a possible interest in perioperative use of physiological sighs. Since the 1980s, the use of these sighs, which were 1.5–3 times as large as the already huge tidal volume and applied 6–10 times per hour was frequent. It is no longer part of the ventilatory strategy, although recruitment maneuvers are recommended during the protective ventilation strategy for some authors [15]. For several decades and until recently, the ventilatory management during surgery has associated high tidal volumes without positive expiratory pressure, high FiO_2, and low respiratory rates.

Currently, a modern approach for ventilation management with protective ventilation should not only take into account tidal volume reduction, but also carefully adjust other important ventilatory parameters, with higher PEEP, higher respiratory rates, and lower FiO_2. This progressive evolution has been influenced by studies on ARDS and by technological improvement of anesthesia ventilators.

Since the initial description of ARDS by Ashbaugh in 1967 [16], animal experimentations [17] followed by several randomized controlled studies in humans [18,19] demonstrated in the late 1990s the negative effects of high tidal volumes in ARDS patients.

There arose a new concern regarding the effects of high tidal volumes in patients without ARDS. Over the 2000s, several studies demonstrated that beneficial effects of low tidal volume ventilation could be present even in non-ARDS context and especially during high-risk surgeries [20,21]. The notion of “iatrogenic” ARDS was described by Gajic et al. [22,23] through two observational studies conducted in patients without pulmonary lesions at admission and among whom an association between the occurrence of acute lung injury (ALI) or ARDS and the use of high tidal volumes had been found, as well as with blood transfusions or pneumonia at admission.

Numerous studies have evidenced the benefits of lung protective ventilation during thoracic, abdominal, and cardiac surgery [21]. More recently, a French multicentric randomized controlled trial,