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FOCUS ON: MECHANICAL VENTILATION IN THE OR

Ventilatory pressure modes in anesthesia

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S U M M A R Y

Mechanical ventilation is a fundamental tool in the clinical daily management of anesthetic procedures and it constitutes a cornerstone in the final evolution of the critical patients. Historically, Volume-controlled ventilation (VCV) has been the universal ventilatory mode used by the anesthesiologists in operating theatre. Nevertheless, since Pressure-controlled ventilation (PCV) was proposed as an alternative to VCV in ICU patients with ALI/ARDS, there has been renewed interest in ventilatory pressure modes in anesthesia. At present the anesthesia workstations usually have available some different modes such as PCV or pressure support ventilation (PSV). The purpose of this review is to evaluate whether ventilatory pressure modes, such as the PCV offer some benefit over the classic VCV, during anesthesia for different types of patients and surgery.

1. Introduction

The earliest mechanical ventilators used on humans were pressure controllers. They were not truly pressure-limited; rather they were pressure-cycled, terminating the inspiratory phase when a set pressure was achieved. However pressure pre-set ventilation fell from favour because of the inability to monitor delivered tidal volume (VT) and to control minute ventilation (VE). In an effort to overcome those limitations, new ventilators that used volume-control were developed. This allowed clinicians better control and regulation of both VT and VE.[1]

During anesthesia the use of volume-controlled ventilation (VCV) is common, as this has been the only available mode on ventilators for a long time. This mode utilizes a constant flow to deliver a target tidal volume (VT) and thus insures a constant minute ventilation, although this may necessitate high-pressures in certain conditions. The mechanical consequences of reduced lung compliance and chest wall compliance (acute respiratory distress syndrome – ARDS-, obesity) added to the reduction of functional residual capacity induced by the surgery (muscle relaxation, trendelenburg, pneumoperitoneum) explain both the impaired alveolar ventilation and the subsequent high-pressures.[2–4]

There was renewed interest in the pressure-limited approach from the early 1980s. Pressure-controlled ventilation (PCV) was proposed as an alternative to VCV in ICU patients with ARDS,[5,6] and in the last few years in anesthesia, to achieve adequate oxygenation and normocapnia in obese patients[7,8]. The two main differences between VCV and PCV are the chosen target and the flow pattern: PCV applies a constant airway pressure (target pressure, not volume) which produces a decelerating flow which reaches the highest possible value at the beginning of inspiration. Flow diminishes throughout the inspiration according to the pressure target, and the resulting VT is variable and depends on the pressure target (limitation) and on the chest-lung compliance. These characteristics of PCV (faster tidal volume delivery, different gas distribution, and high and decelerating inspiratory flow) have been advocated to compensate for any potential reduction in ventilation caused by pressure limitation. Furthermore, the limitation of pressure levels may well have a positive effect on the patient's hemodynamics and might reduce the risk of barotrauma.[5] Debate over the most efficient and safest control mode has continued ever since.

In this review, we analyze the advantages and disadvantages of ventilatory pressure vs volume modes during anesthesia in different types of surgeries and patients. The Table 1 includes the main studies published on this topic.

2. Thoracic surgery and one-lung ventilation

There are some studies that compare PCV versus VCV during one-lung ventilation (OLV) anesthesia by evaluating its effects on airway pressures, arterial oxygenation and hemodynamic state.

In 1997 Tugrul et al. studied 48 patients undergoing thoracotomy.[9] After two-lung ventilation (TLV) with VCV, patients were allocated randomly to one of two groups. In the first group ($n = 24$),

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Table 1
Main studies comparing ventilatory modes used in anesthesia. PCV, pressure-controlled ventilation; VCV, volume-controlled ventilation; TLV, two-lung ventilation; OLV, one-lung ventilation; PSV, pressure support ventilation; MCV, manual-controlled ventilation; ASV, Adaptive support ventilation; PaO_2, arterial oxygen tension; $PaCO_2$, arterial carbon dioxide tension; SpO_2, peripheral oxygen saturation; $EtCO_2$, end-tidal carbon dioxide (mmHg), P(a-Et)CO_2, arterial to end-tidal carbon dioxide partial pressure difference; P(a-Et)O_2, arterial to end-tidal oxygen partial pressure difference; VD/VT, dead space to volume tidal ratio; Ppeak, peak pressure; Pplateau, plateau pressure; Pmean, mean airway pressure; Crs, dynamic compliance of the respiratory system; Raw, airway resistance; Qs/Qt, pulmonary shunt fraction.

Study	Baseline characteristics and modes analyzed	Main Results and differences	Conclusions of the authors and main limitations
Thoracic cavity and OLV			
Tugrul et al[9]	$n = 48$, Crossover trial. Adult patients, TLV & OLV during thoractomy with lung resection PCV vs VCV.	Higher Ppeak, Pplateau, Qs/Qt and lower PaO_2 during OLV in VCV Probable correlation between Improved of PaO_2 and lower FVC during OLV in PCV	PCV may be superior to VCV in patients with respiratory disease. Limitation: there was a weak correlation ($r = -0.3$) between the poor FVC and the PaO_2 improvement to conclude it.
Heimberg et al[10]	$n = 50$, adult patients, TLV & OLV during thoracotomy for minimally invasive coronary artery bypass PCV vs VCV	Higher Ppeak, VD/VT and $PaCO_2$ during OLV–VCV Lower P(a-Et)O_2 and higher PaO_2 during TLV-PCV in the intensive care unit (ICU)	PCV may be useful to improve gas exchange and alveolar recruitment during OLV. The improvement in the oxygenation with PCV was demonstrated only in the ICU 1 h after arrival Limitation: did not include patients with pulmonary disease
Unzueta et al[11]	$n = 58$,, Adult patients, TLV & OLV during thoractomy with lung resection PCV vs VCV.	Higher Ppeak, during OLV–VCV	The use of PCV during OLV does not lead to improved oxygenation, but PCV did lead to lower Ppeak Limitation: did not include patients with pulmonary disease. No advanced hemodynamic monitoring.
Pardos et al[12]	$n = 110$, Adult patients, TLV & OLV during thoracic with lung resection PCV vs VCV.	Higher Ppeak, during OLV–VCV	PCV compared with VCV does not affect arterial oxygenation during OLV Limitation: did not include patients with pulmonary disease.
Choi et al[13]	$n = 18$, Adult patients, OLV during esophagectomy in prone position PCV vs VCV.	Lower Qs/Qt during OLV–VCV, with no any other significant differences.	PCV provides no advantages compared with VCV regard to respiratory and hemodynamic variables during OLV in the prone position. Limitation: did not include patients with pulmonary disease or with morbid obesity
Obese patients			
Cadi et al[8]	$n = 36$, Adult patients, BMI > 35 kg m^2), laparoscopic obesity surgery PCV vs VCV.	Higher pH, PaO_2 and PaO_2/FiO_2 ratio during PCV Lower $PaCO_2$ and P(a-Et)CO_2 during PCV	The changes in oxygenation can be explained by an improvement in the lungs ventilation/perfusion ratio. Limitation: no advanced hemodynamic monitoring.
De Baerdemaeker et al[18]	$n = 24$, Adult patients, BMI > 35 kg m^2), laparoscopic gastric banding PCV vs VCV.	Lower $PaCO_2$ during PCV	PCV provides no advantages compared with VCV regard to respiratory and hemodynamic variables in this patients. ·Limitation: no advanced hemodynamic monitoring.
Zoremba et al[21]	$n = 68$, Adult patients, BMI 25–35 kg m^2), minor surgery PSV vs PCV.	Higher PaO_2/FiO_2 ratio intraoperatively during PSV Better lung function and oxygenation values postoperatively during PSV	PSV better maintains lung function than PCV in moderately obese patients for minor surgery. Limitation: reproducibility during major surgery.
Pediatric patients			
Keidan et al[23]	$n = 32$, 4.5 ± 4 yr, elective surgery with LMA PCV vs VCV	Lower Ppeak with PCV than VCV.	Although no signs of gastric insufflation were detected in both groups, the lower pressures might be significant in patients with reduced respiratory system compliance. Limitation: no hemodynamic data
Bordes et al[24]	$n = 41$, 2–15 yr, elective surgery with LMA PCV vs VCV	Gastric insuflation occurs in one case of PCV and in 3 cases in VCV	PCV may be more efficient than VCV for controlled ventilation with laryngeal mask airway. Limitation: no hemodynamic data
Von Goedecke et al[25]	$n = 20$, 1–7 yr, elective surgery with ProSeal™ LMA. Crossover study. PSV vs CPAP	PSV provides lower inspiratory time fraction, lower $EtCO_2$ and higher VT	PSV improves gas exchange and reduces WOB during ProSeal™ LMA anesthesia compared with CPAP in this type of patients. Limitation: no advanced hemodynamic monitoring
Other type of surgeries and patients			
Natalini et al[26]	$n = 32$, ASA I-II adult patients, general anesthesia with LMA PCV vs VCV	Higher Ppeak during VCV The higher the airway pressure with VCV, the greater was the reduction with VCV	PCV rather than VCV can improve the effectiveness of mechanical ventilation in patients with high airway pressure Limitation: no hemodynamic data