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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

Table 1 (*continued*)

Study	Baseline characteristics and modes analyzed	Main Results and differences	Conclusions of the authors and main limitations
Seet et al[27]	$n = 90$, ASA I-II adult patients, induction of general anesthesia, crossover study	Lower Ppeak during PCV	PCV was associated with lower peak airway pressure, which may provide additional patient safety during positive pressure mask ventilation
	PCV, VCV, MCV		Limitation: no hemodynamic data
Lloréns et al[28]	$n = 22$, ASA I adult women, gynecologic laparoscopic surgery	Despite changes in respiratory mechanics (reduction in Crs and increase in Raw) minute volume was kept constant	In this type of patients, ASV automatically adapted the ventilatory settings to the changes in the respiratory mechanics, keeping constant the pre-set minute ventilation, providing an adequate gas exchange and obviating clinician's interventions
	ASV		Limitation: observational study, it does not allow any comparison with any other types of patients or ventilatory modes
Ogurlu et al[30]	$n = 60$, ASA I-II adult women, gynecologic laparoscopic surgery	Lower Ppeak, Plateau and Raw and higher compliance during PCV after pneumoperitoneum	Both VCV and PCV seem to be equally suited for use in this type of patients
	PCV vs VCV		Limitations: the study lacks blood gas and advanced hemodynamic monitoring. Short duration of the surgery.
Soro et al[31]	$N = 20$, ASA I-II adult women, gynecologic laparotomy surgery in trendelenburg	Lower Ppeak during VCV in trendelemburg	PCV provides no advantages compared with VCV regard to respiratory and hemodynamic variables in this patients.
	PCV vs VCV		Limitations: did not include patients with pulmonary disease or with morbid obesity. The noninvasive measurement of CO and Qs/Qt may have underestimated both parameters.

OLV was started by VCV and the ventilation mode was then switched to PCV. Ventilation modes were performed in the opposite order in the second group ($n = 24$). The peak inspiratory pressure, plateau pressure and pulmonary shunt were all significantly higher during OLV–VCV, whereas arterial oxygen tension was significantly higher during OLV–PCV. Additionally, arterial oxygen tension increased in 31 patients using PCV and the improvement in arterial oxygenation during OLV–PCV correlated inversely with preoperative respiratory function tests. However there was only a weak correlation between PaO_2 values and FVC ($r = -0.3$). The authors conclude that PCV appeared to be an alternative to VCV in patients requiring OLV and may be superior to VCV in patients with respiratory disease.

Nine years later, Heimberg et al[10] studied 50 patients, without pulmonary disease, undergoing thoracotomy and OLV for minimally invasive coronary artery bypass without extracorporeal circulation. After TLV with VCV, patients were divided randomly into two groups: PCV and VCV. Parameters of ventilation, pulmonary function and systemic and pulmonary hemodynamics were recorded intraoperatively (during TLV and OLV) and postoperatively (in the ICU, 1 h after arrival). During OLV–VCV the peak airway pressure, dead space ventilation and arterial carbon dioxide were significantly higher, while in PCV there was lower alveolar-arterial oxygen tension difference and higher arterial oxygen partial pressure at 1 h after arrival in ICU.

In 2007, Unzueta et al.[11] compared both modes during OLV in 58 patients with good preoperative pulmonary function scheduled for thoracic surgery. Airway pressures, arterial oxygenation and hemodynamic state (basic hemodynamic monitoring) were recorded. The patients were prospectively randomized in two groups using a similar design to that in the previous study. Airway pressures and arterial blood gases were obtained during OLV at the end of each ventilator mode. There were no differences in arterial oxygenation between VCV and PCV during OLV, and the only differences were in the peak inspiratory pressures, which were lower in PCV.

In other publication, Pardos et al.[12] studied 110 patients scheduled to thoracic surgery with at least 1 h of OLV. With a similar design to the previous studies, the authors showed that there were no differences between the two modes in arterial oxygenation, airway plateau pressure and mean pressure. Again, the only difference between VCV and PCV was the peak inspiratory pressure that was lower in the latter.

Finally, Choi et al.,[13] compare PCV vs VCV during OLV in the prone position for robot-assisted esophagectomy. Eighteen patients without pulmonary disease were allocated to two groups. There were no differences in arterial oxygen tension, airway pressures, dynamic lung compliance or physiological dead space during OLV between PCV and VCV in the prone position.

To date there are no studies that compare PCV and VCV in terms of inflammatory response and subsequent lung injury to OLV. Lung injury after thoracic[14,15] surgery is relatively uncommon, but when it occurs is a major complication with high mortality. Kutlu et al.[16] showed an incidence of acute lung injury (ALI) and ARDS of 3.9% with a mortality of 72% in patients the ARDS population. Several factors need to be considered as possible triggers for the development of ALI during OLV in thoracic surgery, amongst which mechanical ventilation itself can cause damage to the ventilated lung. The other mechanisms are still not clear, and the evidence for their involvement in ALI after OLV is questionable.[17]

3. Obese patients

Bariatric surgery has become very popular as long-term treatment for morbid obesity (body mass index, BMI > 35 kg m^2) due to the fact that long-term weight loss is better sustained in surgically treated patients compared to conventional treatment. Laparoscopic bariatric procedures are the preferred technique.[18]

In mechanically ventilated and sedated obese patients, derangements in lung and chest wall mechanics have been well documented and include

reduced respiratory system compliance,
increased respiratory system resistance,
severely reduced functional residual capacity
impaired arterial oxygenation.[19]

The reduced lung volumes and the decreased functional residual capacity eventually lead to a ventilation-perfusion mismatch and increased physiological intrapulmonary shunt.[20] Maintenance of adequate oxygenation and avoiding ventilation-induced lung injury is a serious problem in morbidly obese patients. The optimal ventilation mode to achieve these goals in morbidly obese patients is still debated.

There are only two studies,[8,18] with controversial results, comparing the application of VCV or PCV in terms of gas exchange, respiratory mechanics and cardiovascular responses during laparoscopic bariatric surgery.

In the first study,[8] 36 patients (BMI > 35 kg m^2), without major obstructive or restrictive respiratory disease, and $PaCO_2 < 45$ mm Hg were randomized to receive VCV or PCV during laparoscopic gastric banding surgery. Ventilatory settings followed two different algorithms aiming to maintain End-tidal CO_2 ($EtCO_2$) between 33 and 35 mm Hg and plateau pressure as low as possible. PEEP was maintained at 5 cm H_2O. Primary outcome variable was preoperative plateau pressure. Secondary outcomes were PaO_2 (FiO_2 at 0.6 for both groups) and $PaCO_2$ during surgery and 2 h after extubation. The mean pH, SpO_2 and the PaO_2/FiO_2 ratio were all higher in the PCV group, whereas $PaCO_2$ and the $EtCO_2$–$PaCO_2$ gradient were lower (all $p < 0.05$). Ventilation variables, including plateau and mean airway pressures, anesthesia-related variables, and postoperative cardiovascular variables, blood gases, and morphine requirements after the operation were similar. The authors conclude that the changes in oxygenation can only be explained by an improvement in the lungs ventilation/perfusion ratio. Additionally they hypothesized that the decelerating inspiratory flow used in PCV generates higher instantaneous flow peaks and may allow a better alveolar recruitment. However, the study lacked advanced hemodynamic monitoring and VT used in both groups was above 10 ml kg^{-1} IBW.

In the second study,[18] 24 adult patients were ventilated with a VT of 10 ml kg^{-1} ideal body weight, respiratory rate adjusted to obtain an end-tidal carbon dioxide of 35–45 mm Hg, PEEP of 5 cm H_2O, an inspiratory pause of 10% and I/E ratio of 1:2. Fifteen minutes after pneumoperitoneum, the patients were randomly allocated to two groups. In the group VCV ($n = 12$), ventilation parameters were not changed. In the group PCV ($n = 12$), the airway pressure was set to provide a tidal volume of 10 ml kg^{-1} ideal body weight without exceeding 35 cm H_2O. Respiratory rate was adjusted to keep an end-tidal carbon dioxide of 35–45 mm Hg. In the results, at constant minute ventilation, VCV generated same airway pressures, arterial oxygenation and cardiovascular effects with a lower $PaCO_2$ when compared to PCV (42.5 ± 5.2 mm Hg vs 48.9 ± 4.3 mm Hg, $p < 0.01$ ANOVA). A limitation of the study, discussed by the authors was that end-tidal CO_2 may not reflect changes in $PaCO_2$ during pneumoperitoneum because of changes in alveolar dead space, consequent to reduced cardiac output, increased ventilation–perfusion mismatching, or both. These potential influencing factors were measured.

Finally, there is one study evaluating the impact of intra-operative pressure support ventilation (PSV) vs PCV upon early post-operative lung function.[21] In this study 68 moderately obese (BMI 25–35 kg m^2) adults undergoing minor surgery were randomized to receive intra-operative PCV or PSV. The intra-operative oxygenation (PaO_2/FiO_2) in the PSV group was significantly improved over time ($p < 0.0001$). Postoperatively, the PSV group also had better lung function and oxygenation values than did the PCV group ($p < 0.005$). The authors conclude that PSV maintains lung function better than pressure-controlled ventilation in these type of patients. Compared with PCV, ventilation is distributed differently during the spontaneous breathing on PSV. Motion of posterior sections of the diaphragm is better than anterior sections. Consequently, when patients are supine, the dependent lung regions tend to be better ventilated during spontaneous breathing. However, it is difficult to know if these findings can be reproduced in the context of major surgery, as opposed to the minor surgery they examined.

4. Pediatric patients

Mechanical ventilation of pediatric patients, especially infants and neonates, is challenging because small changes in volume can result in unintended hyper-or hypoventilation. Circle anesthesia systems are most commonly used for reasons of efficiency of anesthetic vapour delivery, but classically proved difficult to deliver tidal volume accurately. The complexities of volume delivery when using a traditional circle system led to the adoption of PCV by many pediatric anesthesiologists as the preferred mode of mechanical ventilation. However the new anesthesia ventilators, which compensate for breathing circuit compliance and for fresh gas flow, are able to deliver small tidal volumes accurately under conditions of normal and low lung compliance during VCV.[22]

The laryngeal mask airway (LMA) has gained wide popularity in pediatric anesthesia since its introduction into clinical practice in 1988 and has become one of the essential techniques of airway management. Originally used only as a replacement for the face mask, it is now used successfully in areas where the ETT had previously been considered mandatory. However, ventilation with positive pressure may be a significant limitation to its use, in particular, in pediatric patients, because the classic LMA produces a less effective seal in children than in adults, and a low-pressure seal can be inadequate.[22] There are two studies that compare PCV and VCV in pediatric patients using LMA.

In 2001, Keidan et al.[23] studied 32 ASA I patients, aged 4.5 ± 4 years, who were scheduled for elective procedures under combined general anesthesia and caudal analgesia. After inhalational induction and LMA insertion, each patient was randomly assigned to receive successively PCV and VCV. Peak pressures (PCV) and tidal volumes (VCV) were changed in order to achieve adequate ventilation (end-tidal CO_2 38–42 mm Hg). In the results peak airway pressures were significantly lower with PCV than VCV (14.1 ± 1.6 cm H_2O vs 16.7 ± 2.3 cm H_2O, $p < 0.001$). Hemodynamic parameters, expiratory tidal volume and percent of leak were similar in PCV and VCV. Finally, despite the lower peak pressures obtained during PCV, no signs of gastric insufflation were detected in both modes.

In 2007, Bordes et al[24] compared PCV and VCV in children ventilated through an LMA with the main purpose of determining whether PCV was safer than VCV in preventing gastric insufflation in infants. Forty-one, 2–15 years-old children undergoing general anesthesia with an LMA were studied. The expiratory valve was set at 30 cm H_2O and the leak pressure was measured using constant gas flow. Children were randomly allocated to be ventilated using PCV and VCV for 5 min in order to reach an $EtCO_2$ not exceeding 45 mm Hg, and then they were ventilated with the alternative mode. PCV provided more efficient ventilation than VCV, and the targeted $EtCO_2$ was obtained without gastric insufflation using PCV in all cases except one, whereas VCV failed in three cases.

Finally, pressure support ventilation and continuous positive airway pressure (CPAP) have been studied in pediatric patients with ProSeal™ LMA.[25] Twenty ASA I children, aged 1–7 yr, undergoing general or urologic surgery, were randomized into two equal-sized crossover groups and data were collected before surgery. PSV of 10 cm H_2O above PEEP of 3 cm H_2O was compared with 3 cm H_2O of CPAP. PSV had lower $EtCO_2$ (46 ± 6 versus 52 ± 7 mm Hg; $p < 0.001$), lower inspiratory time fraction ($29\% \pm 3\%$ versus $34\% \pm 5\%$; $p < 0.001$) and higher expired tidal volume (179 ± 50 versus 129 ± 44 mL; $p < 0.001$). There were no differences in the other variables studied (SpO_2, respiratory drive, mean arterial blood pressure, and heart rate). The authors concluded that PSV improves gas exchange and reduces WOB during ProSeal™ laryngeal mask airway anesthesia compared with CPAP in ASA I children aged 1–7 yr.

5. Other types of surgery and patients

There is a study similar to the Keidan et al paper,[23] comparing PCV and VCV during general anesthesia with LMA in 32 ASA I-II adult patients.[26] Patients were ventilated for 3 min both with PCV and VCV, and tidal volume and inspiratory time were kept constant. Peak airway pressure was lower during PCV (14.6 ± 3.5 cm H_2O) than during VCV (16.4 ± 4 cm H_2O). Furthermore, the authors noted that the higher the airway pressure with VCV, the greater was the reduction in airway pressure during PCV.

Seet et al. compared the effect of three modes of positive pressure mask ventilation during induction of anesthesia regarding ventilatory variables and gastric insufflation.[27] They included 90 ASA I-II patients in a prospective, randomized, crossover study. Patients were divided into three groups of different sequence of ventilatory modes. Each patient was ventilated with pressure-controlled ventilation (PCV), manual-controlled ventilation (MCV), and volume-controlled ventilation (VCV). No significant differences were observed in hemodynamic variables and inspiratory and expiratory tidal volumes between the three modes. PCV was associated with lower peak airway pressure (11.4 ± 1.2 cm H_2O) compared with MCV and VCV (14.3 ± 1.7 and 13.3 ± 1.5 cm H_2O; respectively $p < 0.0001$). Gastric insufflation was detected in one patient (1.1%) in the PCV group compared to the three patients (3.3%) in the MCV group and three patients (3.3%) in the VCV group. The authors conclude that in this model of apnoeic patients with an unprotected airway, PCV was associated with lower peak airway pressure which may provide additional patient safety.

One study has tested the efficacy of adaptive support ventilation (ASV) during gynecologic laparoscopic surgery.[28] ASV is a pressure-targeted form of closed loop ventilation, used in ICU, and designed to automatically provide a continuous adaptation to changes in the patient's respiratory mechanics while maintaining a pre-set minute ventilation.[29] The authors studied 22 ASA I women. After induction of general anesthesia, patients were ventilated with ASV. Respiratory mechanics variables, ventilatory setting parameters and analysis of blood gases were recorded at three time points: 5 min after induction (baseline), 15 min after pneumoperitoneum and trendelenburg positioning (pneumo-trend) and 15 min after pneumoperitoneum withdrawal (final). A reduction of 44.4% in respiratory compliance and an increase of 29.1% in airway resistance were observed during the pneumo-trend period. Despite these changes in respiratory mechanics, minute ventilation was kept constant. ASV adapted the ventilatory settings by automatically increasing inspiratory pressure 3.2 ± 0.9 cm H_2O (+19%), $p < 0.01$, respiratory rate by 1.3 ± 0.5 breaths per minute (+9%) and the inspiratory to total time ratio (Ti/Ttot) by 43.3%. At the end, these parameters returned towards their baseline values. Adequate gas exchange was maintained throughout all periods. Therefore, the authors conclude that in healthy women undergoing gynecologic laparoscopy, ASV automatically adapted the ventilatory settings to the changes in the respiratory mechanics, keeping constant the pre-set minute ventilation, providing an adequate gas exchange and obviating clinician's interventions. The study, however, had some limitations: the small numbers of patients, that it did not allow any comparison with any other ventilatory mode and that did not include patients with respiratory disease (therefore no extrapolations can be made with respect to this type of patients).

Other study in gynecological laparoscopic surgery[30] compared the effects of VCV with PCV on respiratory mechanics and noninvasive hemodynamic parameters. Sixty ASA I-II women were randomly allocated to VCV group ($n = 30$) or PCV group ($n = 30$). Variables were recorded: 10 min after induction in the supine position (T1), 15 min after pneumoperitoneum in trendelenburg position (T2), and 10 min after restoration of normal abdominal pressure in supine position (T3). In the results, VCV was associated with a significant increase in peak airway pressure, plateau pressure, and airway resistance at T2 ($p < 0.05$). Compliance was significantly higher in the PCV group at T2 ($p < 0.05$). No other

Table 2
Respiratory and hemodynamic variables in the two modes: 5 min after induction in supine (T1), and 15 min (T2), 30 min (T3) and 45 min (T4) after Trendelenburg positioning.[31] Peak airway pressures were significantly higher (p value < 0.05) during VCV at all times. There were no differences between both modes in the other hemodynamic and respiratory variables during the four times studied (p value > 0.05: NS, not significant). VCV, volume-controlled; PCV, pressure-controlled. Values are shown as mean ± SD. Ppeak, peak pressure (cmH_2O); Pplateau, plateau pressure (cmH_2O); Pmean, mean airway pressure (cmH_2O); RR, respiratory rate (min^{-1}); VT, tidal volume (mL); VE, minute volume (L/min); SpO_2, peripheral oxygen saturation (%); PaO_2/FiO_2, arterial oxygen tension to inspired oxygen fraction ratio (mmHg); $EtCO_2$, end-tidal carbon dioxide (mmHg), P(a-Et)CO_2, arterial to end-tidal carbon dioxide partial pressure difference (mmHg); VDphys/VTe, physiologic dead space to volume tidal ratio; VDA/VTA, alveolar dead space to alveolar tidal volume ratio; Qs/Qt, pulmonary shunt fraction; Crs, dynamic compliance of the respiratory system (mL/cmH_2O); Raw, airway resistance (cmH_2O/L/s); MAP, mean arterial pressure (mmHg); HR, heart rate (min^{-1}); CI, cardiac index (L/min/m^2).

	T1			T2			T3			T4		
	VCV	PCV	*p*	VCV	PCV	*p*	VCV	PCV	*p*	VCV	PCV	*p*
Ppeak	25.1 ± 6.6	18.9 ± 6.9	*0.0005*	25.5 ± 6.4	20.5 ± 5.4	*0.0005*	25.7 ± 6.0	20.8 ± 5.1	*0.0005*	26.9 ± 5.5	22.6 ± 4.9	*0.001*
Pplateu	19.1 ± 5.6	19.9 ± 5.4	NS	19.6 ± 5.9	20.6 ± 5.6	NS	19.6 ± 5.6	20.5 ± 5.3	NS	21.0 ± 4.6	22.3 ± 4.6	NS
Pmean	6.3 ± 1.5	6.2 ± 1.6	NS	6.4 ± 1.6	6.5 ± 1.6	NS	6.3 ± 1.6	6.6 ± 1.4	NS	6.3 ± 1.5	7.2 ± 1.5	NS
RR	12.0 ± 2.6	12.5 ± 1.5	NS	12.5 ± 1.4	12.8 ± 1.4	NS	12.4 ± 1.4	12.8 ± 1.5	NS	12.3 ± 1.3	12.7 ± 1.6	NS
VT	557 ± 82	553 ± 77	NS	566 ± 74	548 ± 71	NS	556 ± 78	555 ± 91	NS	555 ± 77	572 ± 93	NS
VE	6.9 ± 1.1	6.9 ± 1.2	NS	7.1 ± 1.1	7.0 ± 0.9	NS	7.0 ± 1.0	7.1 ± 1.0	NS	6.9 ± 1.3	7.2 ± 1.2	NS
SpO_2	97.7 ± 1.0	97.9 ± 1.3	NS	97.2 ± 1.3	98.3 ± 1.2	NS	97.8 ± 1.3	98.4 ± 1.3	NS	97.2 ± 1.6	98.2 ± 1.3	NS
PaO_2/FiO_2	264 ± 83	282 ± 62	NS	318 ± 95	324 ± 79	NS	304 ± 96	317 ± 83	NS	307 ± 98	327 ± 63	NS
$EtCO_2$	32.5 ± 3.5	32.2 ± 2.9	NS	30.9 ± 3.1	31.7 ± 3.2	NS	29.0 ± 6.7	31.2 ± 3.1	NS	31.0 ± 3.0	30.9 ± 3.9	NS
P(a-Et)CO_2	3.2 ± 3.3	4.5 ± 1.0	NS	6.0 ± 2.8	6.2 ± 2.4	NS	8.1 ± 6.0	7.0 ± 2.3	NS	5.9 ± 2.8	6.1 ± 2.7	NS
VDphys/VT	0.52 ± 0.09	0.64 ± 0.23	NS	0.64 ± 0.11	0.59 ± 0.07	NS	0.65 ± 0.10	0.62 ± 0.12	NS	0.58 ± 0.09	0.60 ± 0.06	NS
VDA/VTA	0.30 ± 0.14	0.51 ± 0.28	NS	0.47 ± 0.14	0.39 ± 0.10	NS	0.43 ± 0.12	0.45 ± 0.16	NS	0.39 ± 0.13	0.45 ± 0.13	NS
Qs/Qt	6.8 ± 2.9	6.3 ± 2.4	NS	7.8 ± 3.1	6.1 ± 1.8	NS	7.7 ± 4.5	7.2 ± 2.3	NS	7.4 ± 3.0	7.3 ± 3.8	NS
Crs	38.9 ± 6.6	38.8 ± 8.7	NS	41.5 ± 11.8	36.9 ± 7.8	NS	38.0 ± 8.3	36.3 ± 6.9	NS	36.4 ± 9.6	34.5 ± 6.3	NS
Raw	13.9 ± 4.7	15.3 ± 3.4	NS	12.1 ± 5.3	14.2 ± 2.4	NS	14.3 ± 3.9	16.2 ± 1.9	NS	15.6 ± 3.5	15.4 ± 2.1	NS
MAP	91 ± 16	87 ± 14	NS	88 ± 14	92 ± 14	NS	84 ± 14	88 ± 13	NS	96 ± 13	92 ± 8	NS
HR	73 ± 13	68 ± 12	NS	72 ± 16	69 ± 19	NS	73 ± 19	70 ± 12	NS	68 ± 9	71 ± 9	NS
CI	3.6 ± 1.1	3.2 ± 0.8	NS	3.3 ± 0.9	3.2 ± 0.8	NS	3.4 ± 0.7	3.2 ± 0.6	NS	3.0 ± 0.2	3.2 ± 0.4	NS

significant differences were found between groups. However some limitations of the study were the absence of blood gas and invasive hemodynamic monitoring, the BMI of the patients (only patients with BMI less than 30 were included) and the short duration of the surgery (the mean operation time was 35–40 min).

Finally we conducted a prospective, randomized and controlled study comparing PCV and VCV during gynecological laparotomic surgery with a duration equal or superior to 90 min.[31] Twenty ASA I-II adult females, without pulmonary disease and BMI 19–26 kg m^{-2} were studied. After induction of anesthesia and tracheal intubation, noninvasive monitoring of cardiac output and intrapulmonary shunt was started with the NICO™ monitor (Respironics, Medical Systems, Wallingford, CT, USA). Additionally the physiologic and alveolar dead space, total dynamic compliance and total airway resistance was recorded with the same monitor. Oesophageal temperature was monitored throughout the procedure and maintained between 36 and 37 °C using a heating blanket placed under the patient. A Julian Ventilator™ (Dräger Medical, Lübeck, Germany) was used for ventilation either VCV or PCV modes. Ventilation settings in both modes were adjusted to maintain end-tidal CO_2 between 30 and 35 mm Hg and tidal volume of 8 mL kg^{-1} IBW. Patients were allocated randomly to one of two groups: In the first group ($n = 10$) ventilation was started by VCV and after 45 min, the ventilation mode was then switched to PCV during other 45 min. Ventilation modes were performed in the opposite order in the second group ($n = 10$). Data were collected at 5 min after induction and supine position (T1), and 15 min (T2), 30 min (T3) and 45 min (T4) after trendelenburg positioning (T5). In the results (Table 2) peak airway pressures were significantly higher ($p < 0.05$) during VCV at all times: T1 (25.1 ± 6.6 vs 18.9 ± 6.9 cm H_2O), T2 (25.5 ± 6.4 vs 20.5 ± 5.4 cm H_2O), T3 (25.7 ± 6.0 vs 20.8 ± 5.1 cm H_2O) and T4 (26.9 ± 5.5 vs 22.6 ± 4.9 cm H_2O). There were no other differences between VCV and PCV at any time in the hemodynamic variables, intrapulmonary shunt, physiologic and alveolar dead spaces, total dynamic compliance and total airway resistance. We conclude that PCV only did lead to lower peak airway pressures compared to VCV without any other hemodynamic or respiratory benefits. This study had several limitations. Firstly, healthy ASA physical status I-II women without underlying respiratory disease or obesity were enrolled in the study, and our results may not be applicable to other populations. On the other hand, the noninvasive measurement of cardiac output and pulmonary shunt used in this study (the partial rebreathing method) may have underestimated both parameters.[32]

6. Conclusions

Along with the classic VCV, ventilatory pressure modes have been incorporated to anesthesia workstations in the last years. PCV has been compared by VCV in different studies, evaluating its effects on airway pressures, arterial oxygenation and hemodynamic state. The majority of the studies conclude that no significative clinical differences between both modes are found when applied in different types of surgery[11–13,18,21,30,31] and patients. The only clear difference is the lower peak airway pressure observed with PCV when compared to VCV. Keeping in mind this difference, PCV may be more efficient than VCV for controlled ventilation with a laryngeal mask in pediatric and adult patients, avoiding gastric insufflation while maintaining equal[23,24,26] ventilation. Other hypothetic advantage of the lower peak airway pressure during PCV might be the decrease of the risk for barotrauma during mechanical ventilation. Nevertheless, in a prospective randomized trial comparing VCV to PCV in 79 patients with ARDS, there were no statistically significant differences in the incidence of barotrauma between both ventilatory modes.[33] Peak airway pressure does not reflect peak alveolar pressure: peak airway pressure is much greater, and depends on endotracheal tube resistance, inspiratory flow, and the respiratory mechanics of the lung. Besides, there is only a weak correlation between peak airway pressure and the incidence of barotrauma.[34] In contrast, there is a strong correlation between plateau airway pressure and mechanical ventilation-induced barotrauma when plateau airway pressure levels exceed 35 cm H_2O.[34]

Regarding to other ventilatory pressure modes, PSV compared with CPAP might be a more adequate mode for the patient in spontaneous ventilation with LMA, where improved gas exchange and reduced WOB.[25] Other ventilatory pressure modes incorporated in ICU ventilators, like the ASV, have been successfully applied in a study on gynecologic laparoscopic surgical patients.[28] In spite of these results, ASV cannot be recommended for routine use in anesthesia yet.

Conflict of interest

None.

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