SCIENTIFIC ARTICLE

Behavior of stroke volume variation in hemodynamic stable patients during thoracic surgery with one-lung ventilation periods

María Lema Tome*, Francisco Andrés De la Gala, Patricia Piñeiro, Luis Olmedilla, Ignacio Garutti

Hospital General Universitario Gregorio Marañón, Departamento de Anestesiología y Reanimación, Madrid, Spain

Abstract

Introduction: In last few years, emphasis was placed in goal-directed therapy in order to optimize patient's hemodynamic status and improve their prognosis. Parameters based on the interaction between heart and lungs have been questioned in situations like low tidal volume and open chest surgery. The goal of the study was to analyze the changes that one-lung ventilation can produce over stroke volume variation and to assess the possible impact of airway pressures and lung compliance over stroke volume variation.

Methods: Prospective observational study, 112 patients undergoing lung resection surgery with one-lung ventilation periods were included. Intravenous fluid therapy with crystalloids was set at $2\,mL.g^{-1}$. Hypotension episodes were treated with vasoconstrictive drugs. Two-lung Ventilation was implemented with a TV of $8\,mL.g^{-1}$ and one-lung ventilation was managed with a TV of $6\,mL.g^{-1}$. Invasive blood pressure was monitored. We recorded the following cardiorespiratory values: heart rate, mean arterial pressure, cardiac index, stroke volume index, airway peak pressure, airway plateau pressure and static lung compliance at 3 different times during surgery: immediately after lung collapse, 30 min after initiating one-lung ventilation and after restoration of two-lung ventilation.

Results: Stroke volume variation values were influenced by lung collapse (before lung collapse 14.6 (DS) vs. OLV 9.9% (DS), $p < 0.0001$; or after restoring two-lung ventilation (11.01 (DS), $p < 0.0001$). During two-lung Ventilation there was a significant correlation between airway pressures and stroke volume variation, however this correlation lacks during one-lung ventilation.

* Corresponding author.
  E-mail: maria.lematome@gmail.com (M. Lema Tome).

Conclusion: The decrease of stroke volume variation values during one-lung ventilation with protective ventilatory strategies advices not to use the same threshold values to determine fluid responsiveness.

Comportamento da variação do volume sistólico em pacientes hemodinamicamente estáveis durante cirurgia torácica com períodos de ventilação monopulmonar

Resumo

Introdução: Nos últimos anos, a importância da terapia alvo-dirigida foi enfatizada para otimizar o estado hemodinâmico do paciente e melhorar seu prognóstico. Os parâmetros baseados na interação entre o coração e os pulmões foram questionados em situações como baixo volume corrente e cirurgia aberta do tórax. O objetivo do estudo foi analisar as alterações que a ventilação monopulmonar pode produzir na variação do volume sistólico e avaliar o possível impacto das pressões da via aérea e da complacência pulmonar sobre a variação do volume sistólico.

Métodos: Estudo observacional prospectivo, no qual 112 pacientes submetidos à cirurgia de ressecção pulmonar com períodos de ventilação monopulmonar foram incluídos. A terapia de fluídos intravenosos com cristaloides foi ajustada a $2\,mL.kg^{-1}.h^{-1}$. Os episódios de hipotensão foram tratados com vasoconstritores. A ventilação dos dois pulmões foi implementada com volume corrente de $8\,mL.kg^{-1}$ e a ventilação monopulmonar foi controlada com volume corrente de $6\,mL.kg^{-1}$. Foi monitorada a pressão arterial invasiva. Registramos os seguintes valores cardiorrespiratórios: frequência cardíaca, pressão arterial média, índice cardíaco, índice de volume sistólico, pressão de pico das vias aéreas, pressão de platô das vias aéreas e complacência pulmonar estática em três tempos diferentes durante a cirurgia: imediatamente após o colapso do pulmão, 30 minutos após o início da ventilação monopulmonar e após a restauração da ventilação dos dois pulmões.

Resultados: Os valores de variação do volume sistólico foram influenciados pelo colapso pulmonar (antes do colapso pulmonar 14,6 [DS] vs. ventilação monopulmonar 9,9% [DS], p < 0,0001), ou após o restabelecimento da ventilação dos dois pulmões (11,01 [DS], p < 0,0001). Durante a ventilação dos dois pulmões houve uma correlação significativa entre as pressões das vias aéreas e a variação do volume sistólico, porém, essa correlação não existe durante a ventilação monopulmonar.

Conclusão: A diminuição dos valores da variação do volume sistólico durante a ventilação monopulmonar com estratégias ventilatórias protetoras sugere não usar os mesmos valores de limiar para determinar a responsividade aos fluídos.

Introduction

During the last few years, emphasis was placed in goal-directed therapy (GDT) in order to optimize patient's hemodynamic status and thus improve their prognosis. These appear to be based on the dynamic parameters used to predict the volume response: stroke volume variation (SVV), pulse pressure variation (VPP) and pulse delta variation. Some authors have recently shown that these hemodynamic parameters may be useful to guide fluid therapy in thoracic surgery.[1–6]

However, other researches have questioned their usefulness in different situations such as the use of a tidal volume (TV) under $8\,mL.kg^{-1}$, under open-chest surgery or during one-lung ventilation (OLV) because of the greater shunt that takes place.[7–9] These circumstances coincide in the regularly handling during protective ventilation in thoracic surgery during OLV.

During OLV, even with protective ventilation, the airflow cut to the prone lung, is associated with a decrease of lung compliance and the increase of airway pressures (Paw). There are different lines of investigation that experimentally have shown that in patients with Acute Respiratory Stress Syndrome (ARDS) the decrease in lung compliance or Paw can disturb SVV values even though a constant blood volume is maintained. However, to our knowledge, this line of research has not been carried out in thoracic surgery. In this type of surgery, the interaction between heart and

lung during OLV have fail to consider the influence of lung compliance or airway pressure when it comes to evaluating the outcomes.

We hypothesized that modifications in ventilatory parameters during open-chest surgery periods may induce changes in hemodynamic parameters based on the interaction between heart and lung.

The goal of our study was to describe the existing changes in the dynamic parameters in patients managed with the same fluid therapy during surgery, and analyze the relationship between the respiratory mechanics (Paw and lung compliance) and SVV setting different TV ($8\,mL.kg^{-1}$ vs. $6\,mL.kg^{-1}$) during open chest surgery (open vs. closed).

Methods

This was a prospective observational study approved by the Hospital Ethics Committee for Clinical Trials. Consecutive sampling was used and all patients gave written consent. One hundred seventy five consecutive patients undergoing elective lung resection with OLV period of at least one hour were studied. Exclusion criteria included pregnant or breast-feeding women, hypersensitivity to any of the anesthetics used, uncompensated cardiac disease or NYHA II patients, atrial fibrillation, or impossibility to achieve protective lung ventilation. Also patients who showed any episodes of hemodynamic instability (defined as a hypotension episodes, MAP < 60 mmHg) were treated with vasoactive drugs and/or fluid bolus were excluded.

After standard monitoring (pulse oxymetry, electrocardiogram and noninvasive blood pressure, urine output), general anesthesia was induced with propofol ($2\,mg.kg^{-1}$), fentanyl ($3\,mcgr.kg^{-1}$) and rocuronium ($0.6-1\,mg.kg^{-1}$). Propofol or sevoflurane (1–2.5%) were used for the maintenance of general anesthesia in order to obtain a BIS (biespectral index) between 40 and 60. A left double-lumen tube was introduced into the trachea (according to a formula based on the patient sex and height: 35–37 for women and 39–41 for men), checking the correct placement by fiberoptic bronchoscopy and auscultation. Patients were connected to mechanical ventilation (Primus Dräger Ventilator. Dräger Hispania SA, Madrid, Spain) and during two-lung ventilation (volume-controlled ventilation) the respiratory parameters set were to tidal volume of $8\,mL.kg^{-1}$, PEEP of 3–5 cm H_2O, and the appropriate respiratory rate to maintain the ETCO$_2$ (end tidal CO_2) between 30 and 35 mmHg, FiO$_2$ used was 0.45. During the OLV period the tidal volume was $6\,mL.kg^{-1}$, PEEP used was 5 cm H_2O, permissive hypercapnia and FiO$_2$ between 0.6 and 1 to maintain SpO$_2$ > 90%. Hypoxemia episodes were treated with an increase of FiO$_2$, CPAP in non-dependent lung and recruitment maneuvers. When the patient was positioned in lateral decubitus, a paravertebral catheter was inserted into the fifth-seven intercostal ipsilateral spaces to the surgical field through a 17 G Tuohy needle using Eason and Wyatt technique.

After general induction, invasive blood pressure using radial artery was monitored via connection to Flo-Trac system (Vigileo, Edwards Lifesciences, Irvine, CA, USA) to measure cardiac output (CO), cardiac index (CI), stroke volume variation (SVV), stroke volume (SV) and stroke volume index (SVI).

Table 1 Demographic and surgery characteristics.

Sex (F/M)	41/71
ASA (I/II/III)	6/67/39
Age (years)	62 (12)
Weight (kg)	68 (11)
Height (cm)	165 (9)
Length OLV (min)	166 (67)
Length anesthesia (min)	285 (84)
FEV1 preop (%)	94 (23)
FVC preop (%)	105 (20)
Segmentectomy	59
Pneumonectomy	3
Lobectomy	58
Bilobectomy	2
Side surgery (L/R)	48/64

Data is presented as mean (SD) and the sample size (*n*).
F, female; M, male; OLV, one-lung ventilation; FEV1 preop, preoperatory forced expired volumen in the first second; FVC preop, preoperatory forced vital capacity; L, left; R, right.

Intravenous fluid therapy with crystalloids was set at a rate of $2\,mL.kg^{-1}.h^{-1}$, maintaining urine output > $0.5\,mL.kg^{-1}$ per hour.

We analyzed the hemodynamic and respiratory parameters at 3 different times during surgery: right before the lung collapse, 30 min after initiating OLV and after two-lung ventilation was restored. In addition to these hemodynamic measurements, blood gases and hemoglobin analysis were sampled.

Statistical analysis was conducted using SPSS (17.0). Pair test was used between basal and OLV and TLV situation, in order to analyze the different hemodynamic and respiratory parameters of the study. In addition, a bivariate correlation analysis was used to determine if the rising between the pressures at the beginning of OLV, the lung compliance decreasing and the SVV increasing. *p*-Values less than 0.05 were considered significant.

Results

A total of 175 consecutive patients undergoing lung resection surgery with OLV periods were included. Eight of them were excluded by atrial fibrillation. Also we excluded another 55 patients who needed fluid boluses or vasoactive drugs during OLV. Demographic characteristics are summarized in Table 1.

During OLV an increase in airway pressures and decrease lung compliance were measured. After restoring TLV (two lung ventilation) these parameters returned to similar values than basal. Among the hemodynamic parameters evaluated, no changes were observed at the beginning of OLV, except by a decrease of SVV values (Table 2). Furthermore, SVV was the only hemodynamic parameter affected when changing to OLV from TLV with close-chest surgery. However, the reset of TLV did not generate those hemodynamic changes.

A significant positive correlation was ground between SVV values and airway pressures (peak, plateau and media pressures) during TLV, right before and after OLV. During OLV no significant correlation between this parameters and airway pressures was noted. Similarly, no significant correlation

Table 2 Hemodynamic and respiratory values during study.

	Basal: before lung collapse	30 min after initiating OLV	*p*-values Basal vs. OLV	Two-lung ventilation restoration	*p*-Values OLV vs. TLV restoration
PaO$_2$/FiO$_2$	371 (138)	117 (50)	0.0001	322 (93)	0.0001
PaCO$_2$ (mmHg)	43 (6)	49 (7)	0.0001	48 (7)	0.114
EtCO$_2$ (mmHg)	33 (4)	35 (4)	0.0001	36 (6)	0.487
Peak pressure (cm H$_2$O)	21 (3)	25 (4)	0.0001	21 (5)	0.0001
Plateau pressure (cm H$_2$O)	19 (3)	21 (5)	0.0001	18 (5)	0.0001
Lung compliance (mL.cm H$_2$O^{-1})	40 (11)	28 (9)	0.0001	42 (15)	0.0001
SVV (%)	14.6 (7)	9.9 (5)	0.0001	11.0 (5)	0.048
HR (Beat.min^{-1})	70 (14)	72 (15)	0.143	74 (14)	0.064
PAM (mmHg)	79 (15)	76 (15)	0.099	78 (15)	0.119
CI (mL.min^{-1}.m^{-2})	2.91 (4)	3.05 (4)	0.177	3.04 (3)	0.942
SVI (mL.beat^{-1}.m^{-2})	37 (13)	37 (11)	0.574	37 (10)	0.968

Data are presented as mean (SD).
CI, cardiac index; MAP, mean arterial pressure; Press, pressure; HR, hear rate, OLV, one-lung ventilation; TLV, two-lung ventilation; SVV, stroke volume variation; SVI, stroke volume index; EtCO$_2$, end tidal of CO$_2$; PaCO$_2$, partial pressure of carbon dioxide; PaO$_2$/FiO$_2$, ratio of arterial oxygen partial pressure to fractional inspired oxygen.
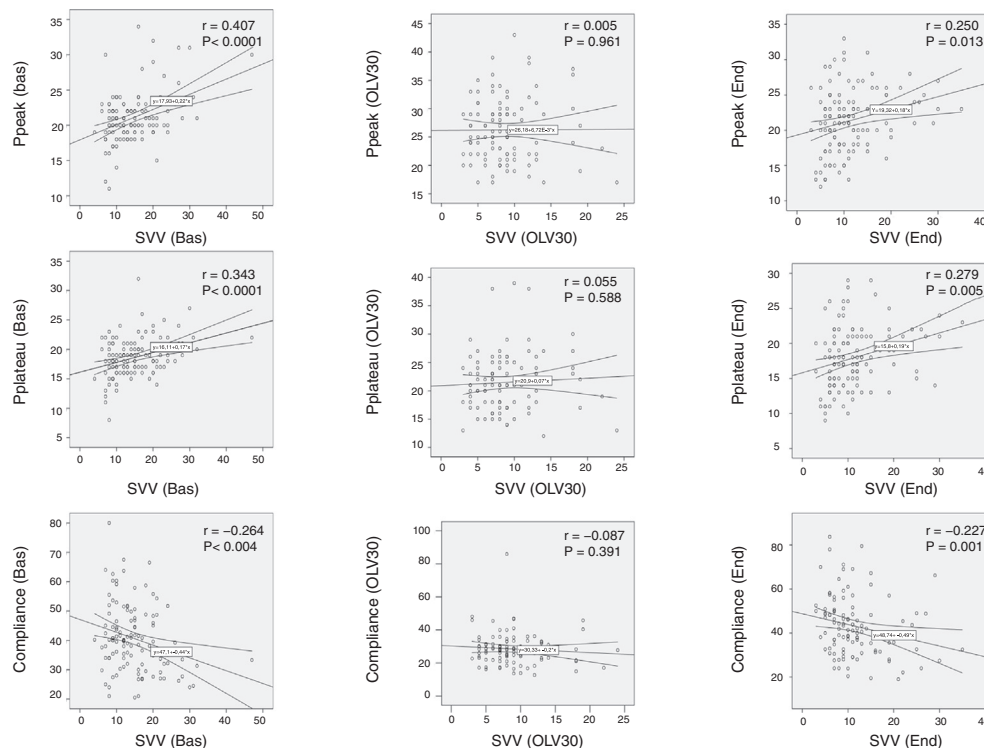

Figure 1 Representation of SVV (stroke volumen variation) during the different times of surgery (BAS, basal; OLV30, 30 min after starting one lung ventilation; End, at the end of one lung ventilation) according to the airway pressures (peak and plateau) and lung compliance.

was found between the rest of the hemodynamic parameters analyzed (MAP, HR, CI, SVI) and the ones provided by the ventilation unit (Fig. 1).

Discussion

The results of this study showed that in hemodynamically stable patients undergo thoracic surgery with OLV periods,

SVV values were the unique hemodynamic parameter which suffer modifications during OLV and these changes reverted after TLV was restored.

The accuracy of a monitoring system used to guide fluid therapy may be critical if GDT is used in this type of surgery where it has been proven an important repercussion of fluid therapy over the acute lung injury or over the respiratory prognosis of these patients.[10,11]

Nowadays the most frequently used parameters in protocols to guide fluid therapy are SVV and VPP, but it is known that they present some limitations which may difficult their use in certain intraoperative circumstances. One of the main limitations in thoracic surgery is the low tidal volume (VT) set during OLV period. VT effect over the absolute value of the dynamic index has been previously examined.[2,12–15] Some authors have observed that SVV is only able to predict the volume response during OLV when a VT of 8 mL.kg^{-1} (ideal weight) or higher was set.[16–18] However, Lee et al. have described that the VPP predictive power is possible to achieve during OLV with a VT of 6 mL.kg^{-1} while when a VT of 10 mL.kg^{-1} was set, VPP was not useful, contravening the physiological basis principles.[19]

The aim of our study was not to evaluate the predictive power of SVV to guide the intraoperatory fluid therapy. We only sought to assess the intraoperatory evolution of the hemodynamic parameters and analyze what the influence of other parameters over the SVV values, since the influence of lung compliance or airway pressures over the values of these indices appear to have been poorly analyzed in clinical practice.

Airway pressures and lung compliance

Considering that the dynamic indices used as a tool for evaluating fluid responsiveness are based on the concept that ventilation with positive pressure induces variations on stroke volume, it is reasonable to assume that these dynamic parameters are affected by the changes on intrathoracic and intrapulmonary pressures such as variation in airway pressures or lung compliance.[20,21]

We observed that patients with higher airway pressures (peak as well as plateau pressure) tend to present higher SVV values. But this finding was only shown when we were ventilating both lungs with a VT of 8 mL.kg^{-1}. During OLV with a low TV the interaction between the airway pressure and SVV was lost. We can explain this finding not only because of the use of low VT but also for the changes in pulmonary blood flow due to the effects of gravity and Hypoxic Pulmonary Vasoconstriction (HPV). Between 20% and 30% of the pulmonary blood flow during OLV will address to the non-ventilated lung, increasing the blood flow in the depended lung, being this lung the one that contributes to fill and unload the left ventricle during the ventilatory cycle. The blood remaining with the pulmonary shunt in the non-ventilated lung will remain unchanged and will not contribute to SVV generation.[22] Besides, shunt magnitude will also influence the dynamic parameters calculus.[18,23]

In addition, during OLV a drastic decrease of lung compliance will occur due to the inlet air in the declined and compressed lung by mediastinum structures, use of rollers to improve the surgical exposure of the hemithorax that goes under surgery, and also because of the pressured exerted by the abdominal content. Mesquida et al. demonstrated in an experimental model how the decreasing lung compliance, while maintaining a constant blood volume, was related to an increase of the dynamic parameters.[24] Lung compliance is also recognized as a factor influencing the intrathoracic pressure.[25] It is known that pulmonary stiffness may buffer the transmission of respiratory pressures

to the cardiovascular system.[26] Monnet et al. observed in patients suffering from ARDS that when the respiratory system compliance was less than 30 mL.cm^{-1} H$_2$O, VPP lost its power to evaluate fluid responsiveness.[27,28] In our study, the increased SVV values during OLV could possibly be explained also by the decrease in lung compliance.

Open chest surgery

Open chest surgery has been another proposed limitation factor of the dynamic indices validity during OLV. Different studies show how under this condition the predictive power of SVV for fluid responsiveness decreases.[29] Although there is some discrepancy in this findings because most of the research was conducted in cardiac surgery, where the ventilatory conditions take place with opened pleura. During OLV we maintain closed pleura in one lung while the one in the non-ventilated lung is open. In this situation, an amount of the pressure generated by the ventilator will be transmitted to the atmosphere instead of the intrathoracic vessels and heart, producing the effect that the ventilation over the volume load will be unpredictable.[17,30–32] In addition, if open chest surgery is combined with other conditions such as OLV and the modification in the pulmonary blood flow to he ventilated lung, the predictable response of fluid administration will be even more complex.

Nevertheless, we do not believe that open chest surgery could influence the lack of relationship between ventilation and SVV because we observed that as the two-lung ventilation was restored (with open pleura) the relationship between the respiratory and cardiac parameters was reestablished. In our study we demonstrated that when we were ventilating two lungs with a VT of 8 mL.kg^{-1} both at the beginning of surgery (close chest surgery) and once again at the end of it (open chest surgery) the relationship between the respiratory parameters (airway pressures and lung compliance) and SVV was significant, but weak, reflecting that the increase of intrathoracic pressure due to mechanical ventilation led a greater variability in left ventricle filling. On the contrary, during OLV (in which we registered higher airway pressures and less lung compliance), setting a low VT (6 mL.kg^{-1}) did not show any affect over SVV. It has to be emphasized another circumstance not always taken into account, being the VT chosen for the dependent lung would be higher than the one used during TLV (4 mL per lung).

Limitations

Likewise, those patients who needed volume administration or vasoconstrictive drugs in order to improve their hemodynamic status were not included in the analysis of the relationship between ventilatory and hemodynamic variables. However we believe that these patients withdrawal could make results more consistent because they could modify the values in presence of hypovolemia or hypotensive periods.

In conclusion, studies that evaluate the usefulness of SVV to detect patients who may benefit the administration of fluid boluses can not use the same threshold values during TLV or OLV. Relationship between cardiorespiratory values

and SVV are lost during OLV with protective ventilation strategies.

Conflicts of interest

The authors declare no conflicts of interest.

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