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Effects of respiratory settings on stroke volume variation derived from the Vigileo^{TM}Flotrac system -comparison with pulse pressure variation-

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Abstract :

Study Objective

To compare the stroke volume variation (SVV) derived from Vigileo^{TM}Flotrac system with the pulse pressure variation (PPV) under different ventilator settings.

Design

Prospective measurement study

Setting

Operating room in the university hospital

Patients

12 patients (ASA physical status 1-2) who underwent elective surgery

Methods

Simultaneous readings of SVV from Vigileo^{TM}Flotrac system and PPV while gradually increasing and then decreasing positive end-expiratory pressure (PEEP) from 0 to 15 cm H_2O in 5 cm H_2O increments.

Main Results

SVV significantly increased with PEEP >10 cm H_2O, being variously 6% ± 2% (PEEP = 0 cm H_2O), 8% ± 2% (PEEP = 5 cm H_2O), 11% ± 6% (PEEP = 10 cm H_2O), 17% ± 10% (PEEP = 15 cm H_2O), 11% ± 8% (PEEP = 10 cm H_2O), 7% ± 3% (PEEP = 5 cm H_2O), and 6% ± 1% (PEEP = 0 cm H_2O). PPV values significantly increased at a PEEP of 15 cm H_2O, being variously 7% ± 4% (PEEP = 0 cm H_2O), 8% ± 4% (PEEP = 5 cm H_2O), 10% ± 4% (PEEP = 10 cm H_2O), 13% ± 5% (PEEP = 15 cm H_2O), 10% ± 4% (PEEP = 10 cm H_2O), 7% ± 4% (PEEP = 5 cm H_2O), and 6% ± 3% (PEEP = 0 cm H_2O).

Conclusions

SVV derived from Vigileo^{TM}Flotrac system was significantly increased under a PEEP of 10 and 15 cm H_2O, although PPV values were not significantly affected at a PEEP of 10 cm H_2O and below. Hence, SVV derived from Vigileo^{TM}Flotrac system might overestimate fluid responsiveness under PEEP > 10 cm H_2O.

Keywords : Vigileo^{TM}Flotrac, Positive End-Expiratory Pressure (PEEP), Stroke Volume Variation (SVV), Pulse Pressure Variation (PPV)

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Introduction

There are still many unknowns regarding perioperative fluid management. With a focus on extracellular fluid volume, the use of massive infusion for the purpose of preventing acute renal failure, a major cause of perioperative death, has become widespread. Recently, however, with the development of bedside monitors that can monitor hemodynamic conditions more easily and

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noninvasively, it has become possible to select a method of fluid management that is individually adapted to the patient's condition. In particular, due to a better prognosis with slightly negative fluid balance in seriously ill patients, there is now a tendency to avoid massive infusion [1]. However, it is difficult to determine the appropriate fluid volumes in real time in the perioperative period. As a result, the assessment of fluid responsiveness has recently become a subject of interest. Fluid responsiveness may be assessed using static parameters based on pressure information (central venous pressure: CVP, pulmonary capillary wedge pressure; PCWP, etc.), static parameters based on volume information (global end-diastolic volume: GEDV, intrathoracic blood volume: ITBV, etc.), and dynamic parameters (stroke volume variation: SVV, systolic pressure variation: SPV, and pulse pressure variation: PPV, etc.). Of these, dynamic parameters (SVV and PPV) have been the most highly evaluated with respect to fluid responsiveness in many studies [2-8]. In addition, recently, a variety of noninvasive cardiac output monitors have been developed, which measure cardiac output based on arterial pressure waveforms, so that dynamic parameters can now be easily measured in a clinical setting; of the dynamic parameters, SVV is the parameter that has attracted the most attention [9]. However, since dynamic parameters involve a method of assessment that utilizes respiratory variations in circulation, it has the potential of being affected by the ventilator settings [10-12]. In particular, with regard to the Vigileo^{TM}Flotrac system, a noninvasive cardiac output monitor that has come to be widely used in recent years, the specific algorithm that it employs is unknown, making various clinical evaluations necessary. The objective of our study was to elucidate the effects of variations in ventilator settings on SVV measured with the Vigileo^{TM}Flotrac system, and to clarify its characteristics by comparison with PPV.

Materials and Methods

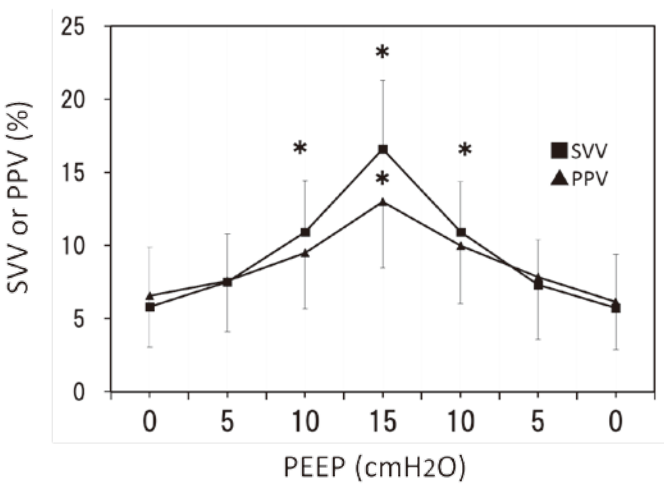
Twelve patients (ASA physical status 1-2) scheduled for elective surgery, who had provided written consent and were approved by the Ethics Review Board of Kochi Medical School, were included in this study. This study was registered with the UMIN Clinical Trials Registry (UMIN 000010252). Premedication was not administered to any of the subjects. After anesthesia induction with oxygen-sevoflurane, fentanyl and rocuronium, a radial artery catheter was inserted for direct measurement of arterial pressure, and the Vigileo^{TM} Flotrac (Edwards Life Science, Irvin, CA, USA) system was attached. Analog signals of the arterial pressure waveforms from a conventional patient monitor (LifeScope J BSM-9100, Nihon Kohden, Tokyo) were inputted to a computer, and the PPV was calculated from the maximum and minimum PP during 32 heart beats. Surgery was performed under general anesthesia maintained with oxygen-sevoflurane, remifentanil and rocuronium. Intraoperatively, respiration and hemodynamics were managed according to the judgment of the attending anesthesiologist, and no limits were placed on intravenous fluid volumes or vascular agents. In the immediate postoperative period and before reversal of anesthesia, after respiration and hemodynamics had stabilized, and with the tidal volume set to 8 ml/kg and the respiratory rate set to achieve an $ETCO_2$ of 35 to 40 mmHg, SVV and PPV values were measured at a PEEP of 0 cm H_2O. Thereafter, PEEP was increased in a stepwise manner with 5 cm H_2O increments up to 15 cm H_2O, followed by a stepwise decrease in 5 cm H_2O decrements, back to a PEEP of 0 cm H_2O.

Statistical analysis

For power analysis, we used data from the pilot study. Using these planning data (mean SVV (SD); 5.8 (2.7) %, mean PPV (SD); 6.5 (2.5) %) to detect a 5 % difference between SVV and PPV, which would be clinically significant, 12 patients were required with $\alpha = 0.05$ and $1 - \beta = 0.80$. Accordingly, 12 patients were enrolled to this study. Statistical analyses were performed using Spearman rank test. Significance was defined as $p < 0.05$. (JMP®11.0.0 SAS Institute Inc. Cary, NC, USA)

Results

The background characteristics of the patients were: Age, 70 ± 9 years old, (8 men and 4 women); height, 157 ± 9 cm, and weight: 58 ± 11 kg. Surgical procedures consisted of total gastric resection in 4 patients, artificial knee joint replacement in 2 patients, myringoplasty in 3 patients, and laparoscopic adnexectomy in 3 patients. Cardiac output and stroke volume values were 4.3 ± 1.0 L/min and 65 ± 13 ml (PEEP = 0 cm H_2O), 4.1 ± 1.0 L/min and 62 ± 13 ml (PEEP = 5 cm H_2O), 3.8 ± 0.9 L/min and 58 ± 14 ml (PEEP = 10 cm H_2O), 3.6 ± 1.2 L/min and 52 ± 12 ml (PEEP = 15 cm H_2O), 3.8 ± 1.0 L/min and 59 ± 12 ml (PEEP = 10 cm H_2O), 4.1 ± 0.9 L/min and 63 ± 11 ml (PEEP = 5 cm H_2O), 4.2 ± 0.9 L/min and 66 ± 11 ml (PEEP = 0 cm H_2O), respectively, the values at a PEEP of 15 cm H_2O being significantly different from those at lower PEEP levels. SVV values were 6% ± 2% (PEEP = 0 cm H_2O), 8% ± 2% (PEEP = 5 cm H_2O), 11% ± 6% (PEEP = 10 cm H_2O), 17% ± 10% (PEEP = 15 cm H_2O), 11% ± 8% (PEEP = 10 cm H_2O), 7% ± 3% (PEEP = 5 cm H_2O), and 6% ± 1% (PEEP = 0 cm H_2O), respectively, the values at higher PEEP (≥ 10 cm H_2O) levels being significantly different from those at lower PEEP levels. Unlike SVV, statistically significant changes were seen in PPV at a PEEP of 15 cm H_2O, the values being: 7% ± 4% (PEEP = 0 cm H_2O), 8% ± 4% (PEEP = 5 cm H_2O), 10% ± 4% (PEEP = 10 cm H_2O), 13% ± 5% (PEEP = 15 cm H_2O), 10% ± 4% (PEEP = 10 cm H_2O), 7% ± 4% (PEEP = 5 cm H_2O), and 6% ± 3% (PEEP = 0 cm H_2O), respectively (Figure). On the other hand, plateau airway pressures, measured as 13 ± 3 cm H_2O (PEEP = 0 cm H_2O), 17 ± 3 cm H_2O (PEEP = 5 cm H_2O), 23 ± 3 cm H_2O (PEEP = 10 cm H_2O), 29 ± 3 cm H_2O (PEEP = 15 cm H_2O), 21 ± 3 cm H_2O (PEEP = 10 cm H_2O), 17 ± 4 cm H_2O (PEEP = 5 cm H_2O), and 13 ± 5 cm H_2O (PEEP = 0 cm H_2O), showed significant changes in proportion with PEEP changes.



Change in SVV and PPV according to PEEP. Closed square represents SVV. Closed triangle represents PPV. *$p < 0.05$ vs PEEP 0cmH_2O

Discussion

Recently, use of the Vigileo™Flotrac system has become common in perioperative hemodynamic and fluid management, because it is able to measure cardiac output and SVV non-invasively in real time [6-8]. However, unlike thermodilution cardiac output measurements, the Vigileo™Flotrac system estimates cardiac output based on standard deviations in arterial pulse pressure, by multiplying these with an independent indicator called χ, which quantifies changes in arterial pressure waveforms and arterial compliance. As a result, it has been pointed out that these measurements could potentially be affected by ventilator settings. In the present study, we investigated the effects of ventilator settings on SVV calculated with the Vigileo™Flotrac system, comparing it with PPV, which is not susceptible to the effects of PEEP [10] and is highly sensitive and specific to fluid responsiveness at levels similar to those of SVV. Our results demonstrated that SVV calculated with the Vigileo™Flotrac system was more strongly affected than PPV by PEEP levels of 10 cm H_2O and above.

In the present study, the maximum airway pressure simultaneously increased because PEEP was varied at a prescribed tidal volume. The resultant respiratory variations, which included changes in arterial pressure waveforms, could not be clearly discriminated from changes due to PEEP alone. On the other hand, with respect to the effects of airway pressure on SVV and PPV, it has been reported that SVV and PPV are affected by plateau pressure even when there is no change in the volume of circulating blood [13]. Thus, based on the results of the present study, it is not possible to clearly identify the mechanism of the effects because the specific algorithms used by the Vigileo™Flotrac system have not been disclosed. More detailed investigations will be required in the future to determine this mechanism.

Moreover, dynamic parameters are circulatory parameters that are strongly affected by the circulating blood volume. To minimize the variety of surgical procedure, we conducted this study in the immediate postoperative period and before reversal of anesthesia under stable respiratory and hemodynamic status. In the present study, the fluid balance varied individually among patients. However, since there was no difference between SVV and PPV before performing the investigations (at a PEEP of 0 cm H_2O), and because their levels returned to control values after the examinations (at a PEEP of 0 cm H_2O), it is believed that circulation was stable, individual differences between subjects were small, and the results of the study remain valid.

Threshold values for predicting fluid responsiveness were reported that SVV was 9.5-10.5% and in PPV was 9-15% respectively [14]. However, in the present study, mean SVV and PPV values were changed from 6 to 17% and 7 to 13% by only applying PEEP without any blood loss. This might be misleading our clinical judgement. Therefore, SVV calculated by the Vigileo™Flotrac system is able to sensitively assess the hemodynamic variations resulting from mechanical ventilation; however, when SVV is used to guide fluid management, infusion must be performed with caution while carefully monitoring the ventilator settings, as the SVV tends to overestimate fluid responsiveness compared to PPV.

Conclusion

SVV calculated by the Vigileo™Flotrac system may overestimate the fluid requirements at a PEEP of 10 cm H_2O and above; hence, SVV levels calculated in this way must be carefully interpreted when PEEP is changed.

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Conflicts of interest

No author declares any conflicts of interest.

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References

[1] Durairaj L, Schmidt GA. Fluid therapy in resuscitated sepsis: less is more. Chest 2008; 133: 252-63.
[2] Cannesson M. Arterial pressure variation and goal-directed fluid thrapy. J Cardiothacic Vasc Anesth 2010; 24:487-97.
[3] Marik PE, Cavallazi R, Vasu T, Hirani A. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature. Crit Care Med 2009; 37: 2642-47.

[4] Zimmermann M, Feibicke T, Keyl C, Prasser C, Moritz S, Graf BM, Wiesennach C. Accuracy of stroke volume variation compared with pleth variability index to predict fluid responsiveness in mechanically ventilated patients undergoing major surgery. Eur J Anaethesiol 2009; 27: 555-61.

[5] Biais M, Bernard O, Ha JC, Degryse C, Sztark F. Abilities of pulse pressure variations and stroke volume variations to predict fluid responsiveness in prone position during scoliosis surgery. Br J Anaesth 2010; 104: 407-13.

[6] Biais M, Nouette-Gaulain K, Quinart A, Roullet S, Revel P, Sztark F. Uncalibrated stroke volume variation are able to predict the hemodynamic effects of positive end-expiratory pressure in patients with acute lung injury or acute respiratory distress syndrome after liver transplantation. Anesthesiology 2009; 111:855-62.

[7] Derichard A, Robin E, Tavernier B, Costecalde, Fleyfel M, Onimus J, Lebuffe G, Chambon JP, Vallet B. Automated pulse pressure and stroke volume variations from radial artery: Evaluation during major abdominal surgery. Br J Anaesth 2009; 103: 678-84.

[8] Cannesson M, Musard H, Desebble O, Boucau C, Simon R, Hénaine R, Lehot JJ The ability of stroke volume variation obtained with Vigileo FloTrac system to monitor fluid responsiveness in mechanically ventilated patients. Anesth Analg 2009; 108: 513-7.

[9] Michard F Stroke volume variation: from applied physiology to improved outcomes. Crit Care Med 2011; 39: 402-3.

[10] da Silva Ramos FJ, de Oliveria EM, Park M, Shettino GP, Azevedo LCP. Heart-lung interactions with different ventilator settings during acute lung injury and hypovolaemia: an experimental study. Br J Anaesth 2011; 106: 394-402.

[11] Wajima Z, Shiga T, Imanaga K. Pneumoperitoneum affects stroke volume variation in humans. J Anesth 2015; 29: 508-14.

[12] Kawazoe Y, Nakashima T, Iseri T, Yonetani C, Ueda K, Fujimoto Y, Kato S. The impact of inspiratory pressure on stroke volume variation and the evaluation of indexing stroke volume variation to inspiratory pressure under various preload conditions in experimental animals. J Anesth 2015; 29: 515-21.

[13] Biais M, Nouette-Gaulain K, Quinart A, Roullet S, Revel P, Sztark F. Uncalibrated stroke volume variation are able to predict the hemodynamic effects of positive end-expiratory pressure in patients with acute lung injury or acute respiratory distress syndrome after liver transplantation. Anesthesiology 2009; 111:855-62.

[14] Renner J, Scholz J, Bein B. Monitoring fluid therapy. Best Pract Res Clin Anaesthesiol 2009; 23: 159-71.