Stroke Volume and Pulse Pressure Variation for Prediction of Fluid Responsiveness in Patients Undergoing Off-Pump Coronary Artery Bypass Grafting*

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Study objectives: **Stroke volume variation (SVV) and pulse pressure variation (PPV) determined by the PiCCOplus system (Pulsion Medical Systems; Munich, Germany) may be useful dynamic variables in guiding fluid therapy in patients receiving mechanical ventilation. However, with respect to the prediction of volume responsiveness, conflicting results for SVV have been published in cardiac surgery patients. The goal of this study was to reevaluate SVV in predicting volume responsiveness and to compare it with PPV.**

Design: **Prospective nonrandomized clinical investigation.**

Setting: **University-based cardiac surgery.**

Patients: **Forty patients with preserved left ventricular function undergoing elective off-pump coronary artery bypass grafting.**

Interventions: **Volume replacement therapy before surgery.**

Measurements and results: **Following induction of anesthesia, before and after volume replacement (6% hydroxyethyl starch solution, 10 mL/kg ideal body weight), hemodynamic measurements of stroke volume index (SVI), SVV, PPV, global end-diastolic volume index (GEDVI), central venous pressure (CVP) and pulmonary capillary wedge pressure (PCWP) were obtained. Also, left ventricular end-diastolic area index (LVEDAI) was assessed by transesophageal echocardiography. Prediction of ventricular performance was tested by calculating the area under the receiver operating characteristic (ROC) curves and by linear regression analysis; $p < 0.05$ was considered significant. All measured hemodynamic variables except heart rate changed significantly after fluid loading. GEDVI, CVP, PCWP, and LVEDAI increased, whereas SVV and PPV decreased. The best area under the ROC curve (AUC) was found for SVV (AUC = 0.823) and PPV (AUC = 0.808); the AUC for other preload indexes ranged from 0.493 to 0.636. A significant correlation with changes of SVI was observed for SVV ($r = 0.606$, $p < 0.001$) and PPV ($r = 0.612$, $p < 0.001$) only. SVV and PPV were closely related ($r = 0.861$, $p < 0.001$).**

Conclusions: **In contrast to standard preload indexes, SVV and PPV, comparably, showed a good performance in predicting fluid responsiveness in patients before off-pump coronary artery bypass grafting.** ***(CHEST 2005; 128:848–854)***

Key words: cardiac preload assessment; cardiac surgery; pulse contour analysis; pulse pressure variation; stroke volume variation

Abbreviations: AUC = area under the curve; CO = cardiac output; CVP = central venous pressure; GEDV = global end-diastolic volume; GEDVI = global end-diastolic volume index; LVEDA = left ventricular end-diastolic area; LVEDAI = left ventricular end-diastolic area index; PCWP = pulmonary capillary wedge pressure; PPV = pulse pressure variation; ROC = receiver operating characteristic; SPV = systolic arterial pressure variation; SV = stroke volume; SVI = stroke volume index; SVV = stroke volume variation; TEE = transesophageal echocardiography

Adequate volume replacement to achieve optimal cardiac performance is a primary goal of hemodynamic management in patients undergoing off-pump coronary artery bypass grafting.[1] Frequently used standard preload indexes such as central venous pressure (CVP) or pulmonary capillary wedge pressure (PCWP) often fail to provide reliable information on cardiac preload and are not capable of predicting a cardiac response to fluid therapy.[2,3] As an alternative to these static variables, assessment of stroke volume variation (SVV, expressed as percentage) has been used as a dynamic monitoring for guiding fluid therapy in patients receiving mechanical ventilation.[4] Cardiac preload is highly susceptible to changes in intrathoracic pressure induced by mechanical ventilation: as stroke volume (SV) varies, systolic arterial pressure variation (SPV) and arterial pulse pressure variation (PPV) can be observed. Both SPV and PPV are pronounced during hypovolemia, and variation decreases if intravascular blood volume is restored; they have shown to reliably predict changes in cardiac output (CO) related to volume replacement.[5–7] However, both SPV and PPV are also influenced by vasomotor tone, which is supposed to be less the case with SVV; therefore, assessment of SVV is thought to be more accurate.[8]

An estimate of both PPV and SVV is displayed in real-time by the PiCCOplus system (Pulsion Medical Systems; Munich, Germany), a continuous CO monitoring device based on arterial pulse contour analysis.[9,10] Conflicting results have been published regarding the clinical use of this SVV variable in cardiac surgery patients: although SVV was able to predict fluid responsiveness in patients after cardiac surgery as reported by Reuter et al,[11,12] Wiesenack and colleagues[13] could not confirm these results in a study performed before cardiac surgery. Both PPV and SVV have been shown to be closely correlated.[14] However, to our knowledge no data on comparison of these variables regarding prediction of fluid responsiveness are available.

The aim of this study was to reevaluate the value of SVV regarding the prediction of volume responsiveness and to compare it with PPV as well as the standard preload variables in a clinical setting in patients before elective off-pump coronary artery bypass grafting.

Materials and Methods

Patients and Anesthesia

With local ethics committee approval and patient written informed consent, 40 patients (American Society of Anesthesiologists class III; mean age ± SD, 62 ± 7 years; body mass index, 27 ± 3; left ventricular ejection fraction, 65 ± 6%) undergoing elective off-pump coronary artery bypass grafting were included in the study. Patients with preoperative dysrhythmias, reduced left and right ventricular function (ejection fraction $< 40\%$), valvular heart disease, intracardiac shunts, pulmonary artery hypertension, or severe peripheral vascular obstructive disease were excluded.

After application of the routine hemodynamic monitoring according to institutional standards (pulse oximetry, five-lead ECG, and noninvasive BP monitoring [CMS; Philips Medical Systems; Andover, MA]) and the insertion of arterial and peripheral IV lines, anesthesia was induced using fentanyl (10 to 30 μg/kg IV), lidocaine (1.5 mg/kg IV), and propofol (up to 2 mg/kg IV) and was maintained with propofol (1.5 to 3 mg/kg/h) and fentanyl. Neuromuscular blockade was achieved with pancuronium bromide (0.1 mg/kg IV). Following endotracheal intubation, mechanical ventilation was performed without positive end-expiratory pressure using an inspired oxygen concentration of 50% and tidal volumes of 10 mL/kg to maintain an end-expiratory P_{CO_2} at 4 to 4.5 kPa during the study period. Effective applied mean tidal volumes were 698 ± 79 mL, and peak airway pressures ranged from 8 to 25 cm H_2O (mean, 17 ± 3 cm H_2O).

Hemodynamic Assessment and Study Protocol

After induction of anesthesia, a standard 7.5F pulmonary artery catheter (Swan-Ganz Thermodilution Catheter; Edwards Lifescience LLC; Irvine, CA) was introduced via right internal jugular vein access. CVP and PCWP were measured using standard transducers and displayed on the monitor (CMS; Philips Medical Systems). Pressure transducers were zeroed at midaxillary level to ambient pressure. A 4F thermistor-tipped arterial catheter (Pulsiocath; Pulsion Medical Systems) was inserted in the left femoral artery and connected to the stand-alone monitor PiCCOplus (computer version 5.2.2; Pulsion Medical Systems). Transpulmonary thermodilution measurements of 15 mL of normal iced saline solution were performed to determine CO and SV. These measurements were made by the same observer to avoid interobserver variation. Global end-diastolic volume (GEDV) is calculated from CO, mean transit time, and down-slope time of the indicator: GEDV = CO × (mean transit time – down-slope time). Transpulmonary thermodilution is used to calibrate pulse contour analysis for continuous CO monitoring and SVV. SVV, as a percentage change of SV during the ventilatory cycle, is assessed according to the following equation: SVV(%) = (maximum SV – minimum SV)/mean SV, where maximum and minimum SV are mean values of the four extreme values of SV during a period of 30 s, and mean SV is the average value for this time period. Additionally, using the PiCCOplus system, PPV can be determined during the same time interval: PPV(%) = (maximum pulse pressure − minimum pulse pressure)/mean pulse pressure, where maximum and mean pulse pressure are mean values of the four extreme values of pulse pressure, and mean pulse pressure is the average value for this time period. The system, the related methods, and the currently used algorithm integrating aortic compliance and systemic vascular resistance have been described in detail elsewhere.[9,15] For transesophageal echocardiography (TEE), a Philips SONOS 5500 system with an Omniplane III TEE probe (Philips Medical Systems, Andover, MA) was used. The probe was positioned to obtain the transgastric, midpapillary, short-axis view of the left ventricle. Left ventricular end-diastolic area (LVEDA) was measured by manual planimetry of the area circumscribed by the leading-edge technique of the endocardial border in this position. LVEDA was determined, recorded, and calculated by the same experienced examiner who was blinded to the results of the hemodynamic measurements throughout the study.

On completion of baseline measurements and prior to any surgical intervention, volume replacement using 6% hydroxyethyl starch solution was performed (mean molecular weight, 130,000 d/mean degree of substitution, 0.4; Voluven; Fresenius Kabi; Stans, Switzerland), 10 mL/kg ideal body weight over 20 min,

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