Stroke volume variations for assessment of cardiac responsiveness to volume loading in mechanically ventilated patients after cardiac surgery

Abstract Objective: We hypothesized that measuring stroke volume variation (SVV) during mechanical ventilation by continuous arterial pulse contour analysis allows the accurate prediction and monitoring of changes in cardiac index (CI) in response to volume administration.

Design and setting: Prospective study in an university hospital.

Patients: Twenty mechanically ventilated patients following cardiac surgery.

Interventions: Volume loading with oxypolygelatin (3.5%) 20 ml × body mass index over 10 min.

Measurements and results: SVV, central venous pressure (CVP), pulmonary artery occlusion pressure (PAOP), left ventricular end-diastolic area index (LVEDAI) by transesophageal echocardiography, intrathoracic blood volume index (ITBVI) by transpulmonary thermodilution and CI were determined immediately before and after volume loading. SVV decreased, while CI, CVP, PAOP, ITBVI, and LVEDAI increased significantly. Percentage changes in CI were significantly correlated to percentage changes in SVV ($r^2=–0.59$, $p<0.001$), ITBVI ($r^2=0.79$, $p<0.001$), and PAOP ($r^2=0.33$, $p<0.05$) and to baseline values of SVV ($r^2=0.55$, $p<0.05$) and LVEDAI ($r^2=–0.68$, $p<0.001$).

Conclusions: SVV may help to determine the preload condition of ventilated patients following cardiac surgery and to predict and continuously monitor effects of volume administered as part of their hemodynamic management.

Keywords Hemodynamic monitoring · Pulse contour analysis · Preload

Introduction

Optimal monitoring of cardiac preload in the critically ill is paramount for precise hemodynamic management, particularly in the postoperative course of cardiac surgery. The effects of extracorporeal circulation together with underlying cardiac pathology are often associated with substantial changes in intravascular volume and hemodynamic status as a cause of possible inflammatory processes, hormonal influences, and pharmacological interactions [1]. Although the Frank Starling mechanism may not apply when myocardial dysfunction is apparent, maintenance of adequate cardiac preload remains the primary target to optimize left ventricular (LV) performance and global oxygen delivery. Therefore parameters reflecting cardiac preload and particularly myocardial responsiveness to volume administration are of particular interest to the clinician.

Various methods for preload determination are commonly used today, principally the measurement of the central venous pressure (CVP) and pulmonary artery occlusion pressure (PAOP). Other monitoring techniques have become accepted in standard practice, such as determining LVEDAI by transesophageal echocardiography.
phy (TEE) [2, 3], which has also recently been validated in cardiac surgery patients, and the intrathoracic blood volume index (ITBV) by indicator dilution technique [4, 5]. Alternative methods for measuring PAOP and CVP have been sought due to concerns regarding the limitations of these values for determining cardiac preload and volume responsiveness [6, 7].

An increase in intrathoracic pressure during inspiration in mechanically ventilated patients leads to a temporary reduction in cardiac preload and therefore to a temporary reduction in stroke volume. These variations in stroke volume can be mapped over the course of the arterial pressure curve, particularly in hypovolemic patients. This systolic pressure variation (SPV) has been described as a highly sensitive parameter for quantifying responsiveness to preload changes [8]. Continuous arterial waveform analysis, based on an algorithm first described by Wesseling et al. [9], has been validated as a method for measuring continuous cardiac output [10, 11] and allows the monitoring of beat-to-beat stroke volumes. Thus this technique allows continuous determination of the variation in stroke volume under mechanical ventilation (stroke volume variation, SVV), which causes SPV.

The aim of this study was to compare the value of routinely used preload parameters to that of SVV in monitoring and predicting cardiac response to volume loading. Twenty cardiac surgery patients were treated postoperatively with a defined intravascular volume challenge. The response of the cardiac index (CI) to volume loading (ΔCI) using thermodilution technique as reference standard for CI, which is susceptible to errors but still remains the clinical gold standard [12, 13], was examined in terms of changes in SVV (ΔSVV) and cardiac filling pressures (ΔCVP, APAOP), ITBV (ΔITBV) and LVEDAI (ΔLVEDAI). Furthermore, the relationship between ΔCI to the baseline preload values prior to volume challenge was investigated to assess the validity of SVV in predicting the hemodynamic response to volume loading.

Materials and methods

Twenty patients were investigated (ten men, ten women) with a mean age of 66 years (range 48–78). Fifteen underwent coronary artery bypass grafting, two aortic valve replacement, and three mitral valve replacement. Patients with a history of occlusive peripheral artery disease were excluded. Preoperative LV cardiac ejection fraction, determined by ventriculography, ranged from 38% to 89% (mean 68%). Patients provided written consent, and the study was approved by the institutional review board. All patients tolerated the study treatment well.

Prior to induction of anesthesia each patient received a 4-F thermodilution catheter (PV2024L, 4-Fr Pulsion catheter, Pulsion Medical Systems, Munich, Germany) inserted into the femoral artery. The catheter enables the monitoring of arterial pressure, cardiac output, additional derived variables by transpulmonary arterial thermodilution, and continuous cardiac output by pulse contour analysis. After induction of anesthesia an 8.0-F central venous catheter (CS-12802, Arrow, Reading, Pa., USA) was inserted into the internal jugular vein. A 7.0-F pulmonary artery catheter (SP5107 Thermodilution Catheter, Ohmeda, Singapore) was also inserted into the internal jugular vein through an 8.5-F introducer and positioned under guidance of pressure curves measured at the proximal and distal port of the catheter. Correct positioning of both catheters was confirmed postoperatively by chest radiography. All transducers (Boghansen V 2TP, Germany; monitoring kit: Abbott Critical Care Systems, Ireland) were positioned at mid-axillary line, calibrated with a mercury manometer and zeroed to atmospheric pressure.

Hemodynamic monitoring

The arterial thermodilution catheter was connected to the monitor for pulse contour analysis and transpulmonary thermodilution (PICCO V 4.1, Pulsion Medical Systems, Munich, Germany). The pulmonary artery catheter was connected to the hemodynamic monitor (Stretocare 1281, Siemens, Solna, Sweden). Three consecutive measurements of cardiac output by transpulmonary thermodilution were performed immediately before the beginning of the study by injecting 10 ml iced saline 0.9% randomly throughout the respiratory cycle into the central venous catheter. These measurements are required for initial calibration of the pulse contour cardiac output (COpc) and additionally generate values of transpulmonary thermodilution cardiac output (COtd) and intrathoracic blood volume (ITBV). Heart rate (HR), systolic (SAP), mean arterial pressure (MAP), and CVP were recorded continuously, as were the COpc, pulse contour stroke volume (SVpc) and SVV. PAOP was determined at end-expiration from a tracing provided by the hemodynamics monitor and averaged from three consecutive respiratory cycles. COad and ITBV were determined by the average of three measurements as described above.

Calculation of SVV

SVV is the variation of beat-to-beat stroke volume from the mean value during a single respiratory cycle and is calculated as: 

$$SVV = \frac{SV_{\text{max}} - SV_{\text{min}}}{SV_{\text{mean}}},$$

where $SV_{\text{mean}}$ is the average of the four 7.5 s intervals were used to calculate SVV.

Calculation of ITBV

ITBV is calculated by measuring the mean transit time and exponential decay time of the thermodilution curve detected in the abdominal aorta [4, 14].

Echocardiographic monitoring

The TEE probe (HP 21364A omniplane probe and HP SONOS Phased Array Imaging System, Hewlett-Packard, Andover, Mass., USA) was positioned to achieve a transgastric midpapillary short-axis view of the left ventricle. This position was maintained during the entire period of data acquisition. TEE images and electrocardiographic signals were recorded simultaneously on video tape and analyzed off-line using a computerized digitizing system (Optimas 3.0, Bioscan, Edmonds, Wash., USA) by an independent reviewer blinded to the condition of the trial subjects. End-diastole was defined as the largest LV cross-sectional area immediately af-