Comparison of stroke volume (SV) and stroke volume respiratory variation (SVV) measured by the axillary artery pulse-contour method and by aortic Doppler echocardiography in patients undergoing aortic surgery

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Background. The goal of the study was to compare stroke volume (SV) and respiratory stroke volume variation (SVV) measured by pulse-contour analysis and aortic Doppler.

Methods. These were measured by pulse-contour analysis and thermodilution (PiCCO) and by aortic pulsed wave Doppler with transoesophageal echocardiography in patients undergoing abdominal aortic surgery. Simultaneous measurements were done at different times of surgery. All data were recorded on PiCCOwin software and videotape and analysed off-line by a blinded investigator.

Results. A total of 114 measurements were achieved in 20 patients. There was a good correlation and small bias between the PiCCO and the echo-Doppler values of the mean SV \( r=0.885; \text{bias}=0.2 \) (8) ml, and between the minimum \( r=0.842; \text{bias}=1 \) (9) ml and maximum SV \( r=0.840; \text{bias}=2 \) (10) ml values.

Conclusions. There is a fair correlation between pulse-contour analysis and aortic Doppler for beat-by-beat measurement of SV but not for calculation of SV respiratory ventilation.

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In mechanically ventilated patients the systolic pressure variation (SPV) and the pulse pressure variation (PPV) have been shown to be sensitive predictors of fluid responsiveness.1–4 However, both SPV and PPV serve in this regard as surrogate measurements of the stroke volume variation (SVV). The respiratory variations of stroke volume (SV), estimated by the measurement of aortic blood flow velocity5 or velocity–time integral,6,7 have also been shown to be sensitive indicators of fluid responsiveness. The introduction of a pulse-contour technique for the measurement of continuous cardiac output (CO) has, however, enabled the real-time measurement of individual SV values, and SVV during mechanical ventilation. SVV, as measured by the PiCCO monitor (Pulsion Medical Systems, Munich, Germany), was also found to be a good indicator of fluid responsiveness,8–10 although one report found a lack of correlation between the SVV and the response of the CO to fluid loading.11 Pinsky12 13 has advised caution in the clinical use of SVV, reasoning that though the mean SV measured by the pulse-contour method has been adequately validated, the arterial pulse-contour technique has not been validated to monitor rapid changes in SV, as may occur over a single breath. Such validation is further complicated by the fact that different monitors use different algorithms for pulse-contour analysis, and therefore the results of any validation process are relevant only to the method studied,
and not to the pulse-contour method in general. Although the validation of PiCCO method for measurement of SV using combined pulse-contour and transpulmonary thermodilution has already been done by comparison with pulmonary thermodilution, both methods are equally based on the same Stewart–Hamilton principle. Using a different method, based on completely different physiological principle (Stewart–Hamilton vs Doppler), may improve the validation of the PiCCO system.

We have therefore compared mean values of SV, rapid changes of SV (minimum and maximum SV) and the derived SVV, as measured by the PiCCO monitor, to similar data measured by aortic Doppler during transoesophageal echocardiography (TOE). The study was done in patients undergoing vascular surgery and axillary artery thermistor-tipped catheters were used to measure CO and to obtain the arterial pressure waveform for pulse-contour analysis.

Methods

After approval of the study protocol by the institutional review board, 23 consecutive patients undergoing major aortic (aorto-aortic or aorto-femoral bypass) surgery were included in the study. Patients were informed of the use of continuous CO monitoring with the PiCCO system and assessment of cardiac function with TOE during surgery. Exclusion criteria included the presence of atrial fibrillation, aortic valve disease (detected after operation by transthoracic echocardiography) and significant stenosis of the subclavian artery detected preoperatively as part of the Doppler examination of the carotid arteries.

Preoperatively and intraoperatively patients were managed according to the standard clinical practice of the vascular anaesthesia unit. Our routine intraoperative monitoring for major vascular surgery includes the insertion of a central venous catheter, an arterial catheter for continuous arterial pressure recording and the use of TOE throughout the procedure. A 4F thermistor-tipped catheter (Pulsion Medical Systems, Munich, Germany) was introduced into the axillary artery as described previously.14 The cannulation of the axillary artery was done under local anaesthesia in the awake patient before induction of anaesthesia, using a sterile technique. The arterial catheter was then connected to the PiCCO monitor for haemodynamic measurement. After induction of anaesthesia and endotracheal intubation, the patient’s lungs were ventilated with a tidal volume of 8 ml kg⁻¹ and no PEEP, while maintaining anaesthesia with a continuous infusion of propofol and sufentanil. The ventilatory frequency was initially set up in order to keep end-tidal Pco₂ between 3.99 and 4.66 kPa and was unchanged during the study period. The range of ventilatory frequencies among patients was 12–16 min⁻¹. A transoesophageal multiplane probe was then inserted for routine haemodynamic monitoring. Simultaneous measurements by both PiCCO and TOE were done after induction of anaesthesia, before and after aortic cross-clamping, before and after aortic declamping and after fluid challenges consisting of 500 ml of plasma expander (Plasminon, Kabi Pharma, France), which were administered based on clinical judgement and repeated whenever they induced an increase of ≥15% in the Doppler aortic CO value.

PiCCO measurements

CO was measured in triplicate by the injection of NaCl solution 0.9% (15 ml) at a temperature below 8°C through the central venous catheter, with the thermodilution curve being measured by the axillary artery thermistor-tipped catheter.14 This CO value calibrates automatically the pulse-contour based measurement of continuous SV, with the latter being displayed in the dedicated data acquisition software (PiCCOwin, Pulsion Medical Systems) as individual, mean, maximal or minimal values. In addition, the SVV is automatically calculated using the formula:

\[ SVV(\%) = \left( \frac{SV_{max} - SV_{min}}{SV_{mean}} \right) \times 100 \]

where \( SV_{max} \) and \( SV_{min} \) denote the mean maximum and minimum SV values, respectively, identified during four consecutive periods of 7.5 s. The \( SV_{mean} \) is the mean SV calculated over a floating mean of 30 s. All PiCCO data were recorded on a PC using dedicated software. Another triplicate bolus CO measurement was done for the calibration of the pulse-contour derived parameters before each data collection.

TOE measurements

Before each measurement, the TOE probe was positioned to obtain the deep trans-gastric longitudinal view of the heart and an alignment with the aortic root. All echo-Doppler measurements were recorded on videotape with the simultaneous airway pressure trace. The echo-Doppler data were recorded by a trained observer and analysed off-line by another investigator blinded to the PiCCO results. Synchronicity of both Doppler and PiCCO measurements was ensured by making a signal on the PiCCOwin software at the end of each echo measurement.

The aortic valve area was calculated from the left ventricular outflow tract diameter (LVOTd) measured at the insertion of the aortic cusp as \( \text{LVOTa (cm}^2) = \pi \times (\text{LVOTd/2})^2/4 \). The mean echo-Doppler SV was obtained by multiplying the LV outflow tract area (LVOTa) by the aortic flow velocity–time integral (VTIao) using the formula \( \text{SV (ml)} = \text{LVOTa (cm}^2) \times \text{VTIao (cm)} \). The mean echo-Doppler SV (SV-E mean) was calculated as the average of six consecutive beats. Echo-Doppler calculation of CO was obtained by multiplying the SV-E mean by the heart rate. The maximum and minimum SV values were identified.
during four consecutive respiratory cycles and averaged to obtain SV-E_{\text{max}} and SV-E_{\text{min}}, respectively.

All results are expressed as mean (SD). Statistical analysis was performed using statistical software (Staview 5.0; SAS Institute, Cary, NC). The echo-Doppler and PiCCO measurements were compared by linear regression using least square variables to evaluate proportional (slope of curve) and constant (y-intercept) errors and bias (agreement), the limits of agreement (SD 2) according to the Bland–Altman method and the precision (absolute value of difference between variables). Statistical significance was considered to be at $P<0.05$.

### Results

Of the 23 patients, one patient was excluded because of a suboptimal arterial pressure trace, and two others were excluded because of suboptimal alignment of the TOE probe with the LVOT, because of anatomical causes.

A total of 114 measurements were obtained in the 20 patients who were included in the final study population. The median number (range) of measurements per patient was 6 (5–7).

There was a fair correlation and small bias between the PiCCO and the echo-Doppler values of the minimum and maximum SV (Table 1, Figs 1 and 2) and with the mean SV

Table 1  SV_{\text{min}}, minimum SV; SV_{\text{max}}, maximum SV; SV_{\text{mean}}, mean SV; SVV, stroke volume variation. These values are expressed as mean (SD). $r$, Correlation coefficient. Statistical significance was considered for $P<0.05$. Bias and Precision are expressed as mean (SD). Precision is expressed with the same unit, ml for SV and % for SVV.

<table>
<thead>
<tr>
<th></th>
<th>PiCCO</th>
<th>Doppler</th>
<th>$r$</th>
<th>$P$-value</th>
<th>CI</th>
<th>Slope</th>
<th>$y$-Intercept</th>
<th>Bias</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV_{\text{min}} (ml)</td>
<td>68 (17)</td>
<td>69 (15)</td>
<td>0.842</td>
<td>&lt;0.0001</td>
<td>0.78–0.89</td>
<td>0.950</td>
<td>2.4</td>
<td>1 (9)</td>
<td>7 (6)</td>
</tr>
<tr>
<td>SV_{\text{max}} (ml)</td>
<td>76 (18)</td>
<td>78 (17)</td>
<td>0.840</td>
<td>&lt;0.0001</td>
<td>0.78–0.89</td>
<td>0.905</td>
<td>5.7</td>
<td>2 (10)</td>
<td>8 (6)</td>
</tr>
<tr>
<td>SV_{\text{mean}} (ml)</td>
<td>72 (17)</td>
<td>72 (16)</td>
<td>0.885</td>
<td>&lt;0.0001</td>
<td>0.84–0.92</td>
<td>0.968</td>
<td>2.1</td>
<td>0.2 (8)</td>
<td>6 (5)</td>
</tr>
<tr>
<td>SVV (%)</td>
<td>11 (6)</td>
<td>12 (6)</td>
<td>0.661</td>
<td>&lt;0.0001</td>
<td>0.54–0.75</td>
<td>0.649</td>
<td>3.25</td>
<td>1 (5)</td>
<td>4 (3)</td>
</tr>
</tbody>
</table>

Fig 1  Linear correlation (a) and Bland–Altman analysis (b) of minimum stroke volume (SV) measured with Doppler (SV_{\text{min}}-D) and with PiCCO (SV_{\text{min}}-P).

Fig 2  Linear correlation (a) and Bland–Altman analysis (b) of maximum SV measured with Doppler (SV_{\text{max}}-D) and with PiCCO (SV_{\text{max}}-P).
Although the mean SVV values were similar when measured by the echo-Doppler and by the PiCCO, the correlation coefficient (r) of SVV measured with echo-Doppler (SVV-E) and with PiCCO (SVV-P), though significant, was only 0.661 with a bias of 1 (5)% (Table 1, Fig. 4).

Discussion
The recent re-introduction of arterial pressure pulse-contour analysis enables the measurement of continuous CO and beat-by-beat SV. This method has been validated by studies that have shown good agreement between CO and mean SV measured by pulse-contour analysis and those measured by the pulmonary thermodilution method. Both thermodilution methods are based on the Stewart–Hamilton principle. The results of our study show for the first time that the mean SV determined by the pulse-contour analysis of the PiCCO system are in good agreement with echo-Doppler measurements.

In addition, the ability to measure individual SV by the pulse-contour method has enabled the introduction of continuous measurement of SVV on some monitors. SVV is a measurement of the change of SV during a mechanical breath. Normally, the main haemodynamic effect of a mechanical breath is a transient decrease in LV preload. However, a more preload-dependent patient will demonstrate a larger decrease in SV and will have, as a consequence, a larger SVV. This principle has been applied successfully, both experimentally and clinically, using SPV and PPV, which have been shown to reflect fluid responsiveness much better than filling pressures or volumetric measures of preload such as the global end-diastolic volume (GEDV) and the LV end-diastolic area. However, variations in systolic pressure and pulse pressure serve only as surrogates of SV and, potentially, a direct measurement of SVV may be more accurate.

Nevertheless, like any other new monitored variable, the pulse contour-derived SVV needs to be adequately validated so that its accuracy and limits of performance are well recognized. Such validation process can and should be done by comparing the SVV to a ‘gold standard’ measurement, by assessing its individual performance as a fluid-predictor, and by comparing it to similar methods (e.g. SPV, PPV) that have been tested previously. Moreover, as different pulse-contour methods use different algorithms, each method has to be individually validated.
measured by the PiCCO monitor has been shown to perform well as predictor of fluid responsiveness.\textsuperscript{8,10} Two separate groups of investigators have found an SVV cut-off value of 9.5% to predict a positive response of the CO to fluid loading in patients undergoing neurosurgery\textsuperscript{8} and cardiac surgery.\textsuperscript{9} In one of these studies, however, SVV had a lesser predictive value in patients with a low preoperative ejection fraction and higher intraoperative LV end-diastolic dimensions compared with patients with normal preoperative cardiac function.\textsuperscript{16} Another study, in cardiac surgery patients, found no significant relationship between baseline SVV values and the percentage change in CO from the echo-Doppler SVmax and SVmin values and SVV during at least one respiratory cycle. It is possible that the observed difference in the calculated SVV values stem from a different timing of the two methods. We tried to synchronize both measurements by marking the echo-Doppler SVmax and SVmin values on the monitor screen. This reason for this variability is not clear but may be the main reason for the differences observed between PiCCO and echo-Doppler SVV data.

There is a fair correlation between pulse-contour analysis and aortic Doppler for beat-by-beat measurement of minimal, maximal and mean SV during aortic surgery but not for calculation of SV respiratory variation.

References

2 Tavernier B, Makhotin E, Lebuffe G, Dupont J, Scherpereel P. Systolic pressure variation as a guide to fluid therapy in patients with sepsis-induced hypotension. Anesthesiology 1998; 89: 1313–21
11 Wiesenack C, Prasser C, Rodig G, Keyl C. Stroke volume variation as an indicator of fluid responsiveness using pulse contour...


19 Perel A, Pizov R, Cotev C. Systolic blood pressure variation is a sensitive indicator of hypovolemia in ventilated dogs subjected to graded hemorrhage. Anesthesiology 1987; 67: 498–502
