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Assessing Fluid Responsiveness by Stroke Volume Variation during One-Lung Ventilation

Ekta Singla[1], Sakshi Arora[2]*, AK Bhargava[3] and Amish Chaudhary[4]

[1]*Department of Anaesthesia, Guru Gobind Singh Govt Hospital, Delhi*

[2]*Department of Anaesthesia, ESIC Hospital, Rohini, Delhi*

[3]*Department of Anaesthesia, Rajiv Gandhi Cancer Institute and Research Centre, Rohini , Delhi*

[4]*Senior Consultant, Oncosurgery, Max Saket Hospital, Delhi*

***Corresponding Author:** Sakshi Arora, Department of Anaesthesia, ESIC Hospital, Rohini, Delhi.

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Introduction

Intravascular volume status has traditionally been measured with observation of heart rate; mean arterial pressure, urine output and other hemodynamic variables. However, these parameters are known to lack sensitivity & objectivity and it is sometimes difficult to assess fluid shifts from central to peripheral compartment. Thus, this study was designed to evaluate an accurate functional hemodynamic parameter for assessment of fluid requirement. The ideal indicator for fluid responsiveness should be accurate, simple, minimally invasive, not influenced by cofactors and with minimal complication rate. In the present study, we tried to establish the accuracy of one such variable i.e. Stroke Volume Variation (SVV) with the help of minimally invasive Pulse contour Analyser (Edwards Vigileo FloTrac monitor).

Aims and Objectives

The aim of the study is to ascertain whether the stroke volume variation and cardiac index can serve as a predictor for adequate fluid replacement in mechanically ventilated patients during one lung ventilation. The objective would be to study stroke volume variation before and after significant blood loss and after adequate replacement with plasma expander.

Materials and Methods

After obtaining institutional Research Ethical Committee Approval and informed patient consent, a randomized study was conducted at tertiary care hospital.

Equipment Details

V1GILEO Monitor (EDWARDS VIGILEO SN: VLOO 3786) monitor that measures cardiac function parameter based on Pulse Contour Analysis and requires arterial cannula insertion was used for the study. Apart from measuring the invasive intra-arterial BP it computes the pulse contour to analyze the cardiac output. The monitor has a number of advantages.

1. Is less invasive
2. Continuously computes SV from patient's arterial pressure signal.
3. Displays key hemodynamic parameters on a continuous basis (every 20 sec).
4. Requires no manual calibration

5. Has rapid set up and applications
6. Is easy to use

The user has to enter patients' age, gender, height and weight to initiate the monitoring. Advance wave form analysis compensates for patient to patient difference in vasculature; real time changes in vascular tone; differing arterial site. However, care must be taken to avoid dampening, kinking lines, and leveling of sensor. The combination of the FlowTrac sensor & Presep oximetery catheter provides a comprehensive continuous view of patient's balance between oxygen delivery and consumption in a minimally invasive, easy to use platform. The FlowTrac sensor is a less invasive hemodynamic monitoring device that, when used with Vigileo monitor measures CCO through any existing arterial pressure line. The Vigileo monitor uses the patient's existing arterial pressure waveform to continuously measure CO.

FlowTrac sensor measures the variations of arterial pressure which is proportional to SV. A robust algorithm compensates for individual patient's vessel compliance and changes in vascular tone, there by not requiring any external calibration. CO is displayed on a continuous basis by multiplying the pulse rate and calculated SV as determined form pressure waveform. For the FlowTrac sensor to accurately report CO one must zero the arterial pressure reading on Vigileo monitor and the bed side monitor. The monitor comprises of a sensor, processing and display unit.

Sensor: the specially designed sensor provides the high fidelity arterial pressure signal required by the monitor to calculate the stoke volume. It is a transducer that preprocesses and sends signal to Vigileo monitor.

Processing Unit: It applies proprietary algorithm to digitalized wave and reports cardiac output, cardiac index, stroke volume variation and stroke volume index. SVR can be calculated if the value of CVP is fed into the system

Methodology

30 patients of either sex, aged 25-75yrs belonging to ASA grade I- III scheduled for thoracotomies requiring one lung ventilation were included in the study.

Exclusion Criteria

1. Patients with left ventricular ejection fraction <0.35
2. Patient with hemoglobin< 12.0gm%
3. Patients with history of arrhythmias

The preoperative assessment included a detailed pulmonary function analysis, cardiac and neurological analysis.

Study Group: The group comprised of 30 patients. Hemodynamic parameters of all patients were determined at five points (T_0, T_1, T_2, T_3, T_4)

(T_0) Prior to opening chest in supine position
(T_1) Prior to opening chest in lateral position
(T_2) After opening chest
(T_3) After 500ml of blood loss
(T_4) After supplementation with 500 ml of voluven

Control Group: In the study all the patients served as their own control and hemodynamic measurements taken at T_1 (before opening chest) and 15 minutes after opening chest (T_2) served as the control group. During this interval no surgical manipulation was performed.

Anaesthetic Technique: The patients were pre-medicated with diazepam orally 5 mg, Ranitidine 150 mg (a night before the surgery), Diazepam 5 mg, Ranitidine 150 mg and Graniseteron hydrochloride 2 mg on day of surgery (two hrs before the surgery). In the operation

theatre after checking all the vital parameters, an epidural catheter was placed for intra-operative and post operative pain relief. Patients were induced with injection morphine 0.1mg/kg, injection propofol 1-1.5 mg/kg and neuromuscular block was achieved with injection atracurium 0.5 mg /kg. Injection Fentanyl 1µgm/kg were given just prior to intubation. Intubation was done by double lumen tube, univent tube, or bronchial blocker. The correct position of the tube was checked by auscultation and confirmed by Fiberoptic Bronchoscope in supine as well as later in lateral decubitus position. Central venous cannulation (Internal juglar/Subclavian) and arterial cannulation were performed after induction of anesthesia for monitoring the hemodynamic parameters. Anesthesia was maintained by O_2, N_2O and volatile anesthetics till thorax was opened. On opening the thorax, N_2O and volatile agents were discontinued and maintenance was done with propofol infusion. Analgesia was provided through systemic and neuraxial routes from time to time and muscle relaxant infusion was given to keep the post tetanic contraction around 8-10. During one lung ventilation, tidal volume and ventilatory rates were adjusted to maintain end tidal PCO_2 of 35-45mm of Hg and to maintain Paw below 30 cm of water. I: E: 1:2, Positive End Expiratory Pressure (PEEP) to the ventilated lung and Continuous Positive Airway Pressure (CPAP) to atelectic lung were recorded.

All the patients tolerated the study regimen well. All the patients were haemodynamically stable and did not require any pharmacological support with vasopressors or catecholamine. Continuous monitoring of PR, Blood Pressure, CVP, CO, CI, SV, SVV, Blood loss, SVR, SVRI, Airway Pressure(Paw) and values at T_0, T_1, T_2, T_3, T_4 were recorded. Variation in values T_1, T_2, T_3 and T_4 were analyzed by paired Student's-t test.

Results and Observations

The study was carried out in 30 patients of either sex aged 25-75 yrs, ASA grade I-III, scheduled for thoracotomies requiring one-lung ventilation.

Demographic Data

Mean Height = 162.63 ± 6.69cm
Mean Age = 55.90 ± 10.23yrs
Mean Weight =60.40 ± 10.50Kgs
Sex Ratio: Male: female: 23:7
Thoracotomies: Right: left: 14:1
Type of Surgery:
Right Lobectomy: NIL
Right Pneumectomy: 4
Lt. Pneumonectomy: 2
Oesophagectomies: 24

The monitoring parameters, as described, at T_0, T_1, T_2, T_3 and T_4 were recorded. The table 1 depicts the average value at T_0 and the subsequent changes at T_1, T_2, T_3 and T_4

Time	Mean PR (min^{-1})	Mean MAP (mm Hg)	Mean CVP (mm Hg)	Mean CO (L min^{-1})	Mean CI (L min^{-1} m^{-2})	Mean SV (ml $beat^{-1}$)	Mean SVV (%)	Mean SVR (dynes $sec^{-1}cm^{-5}$)	Mean SVRI (dynes.sec. cm^{-5} m^{-2})	Mean Paw (mm of H_2O)
T_0	78.47	84.13	8.03	5.48	3.35	68.73	6.90	1196.40	1990.60	17.10
T_1	71.53	84.67	5.57	5.90	3.67	70.73	7.33	1140.50	1868.30	18.23
T_2	85.00	95.20	8.03	6.08	3.74	70.33	7.43	1235.57	2010.83	23.97
T_3	84.93	89.47	8.60	5.38	3.28	63.97	14.40	1238.40	2008.70	22.30
T_4	85.47	91.60	8.13	6.05	3.73	69.53	7.43	1154.03	1881.17	22.07

Changes in all the variables from supine (T_0) to lateral (T_1), from closed chest in lateral position (T_1) to open chest in lateral position (T_2), from T_2 i.e. when no blood loss had taken place to T_3 i.e. after 500 ml of blood loss, from 500 ml of blood loss (T_3) to replacement with volume (T_4) were analyzed. Thus changes between T_0 and T_1, T_1 and T_2, T_2 and T_3, T_3 and T_4 were compared using paired Student's t- test. p value < 0.05 was considered significant and p-value <0.001 was considered highly significant. Table 2 compares values between T_0 and T_1. Changes in CVP CI, PR were significant. However changes MAP, CO, SV, SVV, SVR, SVRI and Paw were insignificant.

Time → T0 ↓ Variables		T1	Changes t(P- Value)
PR	78.47 ± 15.48	71.53 ± 18.85	0.027341
MAP	84.13 ± 12.78	84.67 ± 13.07	0.849857
CVP	8.03 ± 4.14	5.57 ± 2.78	0.001052
CO	5.48 ± 1.32	5.90 ± 1.54	0.09989
CI	3.35 ± 0.79	3.67 ± 0.89	0.036452
SV	68.73 ± 13.06	70.73 ± 11.86	0.404467
SVV	6.90 ± 1.92	7.33 ± 2.14	0.382064
SVR	1196.40 ± 327.65	1140.50 ± 311.06	0.245856
SVRI	1990.60 ± 553.20	1868.30 ± 413.33	0.129282
Paw	17.10 ± 5.26	18.23 ± 5.74	0.197204

Table 2: *Comparison of T_0 and T_1.*

Table 3 depicts the comparison of various variables at T_1 and T_2. PR, MAP, Paw were highly significant (p < 0.001). CVP and SVRI was significant (p < 0.05). CO, CI, SV, SVR were not significant (p > 0.05).

Time → T0 ↓ Variables		T1	Changes t(P- Value)
PR	71.53 ± 18.85	85.00 ± 14.28	0.000121
MAP	84.67 ± 13.07	95.20 ± 14.55	0.000225
CVP	5.57 ± 2.78	8.03 ± 4.09	0.003228
CO	5.90 ± 1.54	6.08 ± 1.61	0.194353
CI	3.67 ± 0.89	3.74 ± 0.98	0.385228
SV	70.73 ± 11.86	70.33 ± 12.88	0.842725
SVV	7.33 ± 2.14	7.43 ± 2.28	0.66921
SVR	1140.50 ± 311.06	1235.57 ± 388.02	0.074179
SVRI	1868.30 ± 413.33	2010 ± 596.97	0.042418
Paw	18.23 ± 5.74	23.97 ± 7.69	2.03 E -.05

Table 3: *Comparison of T_1 and T_2.*

The values of all the variables at T_2 and T_3 were recorded. The values of C0, CI, SVV were highly significant (p < 0.001) but out of these SVV was the most significant (p value = 1.82E-14). SV & MAP were significant (p < 0.05) while PR, CVP, SVR, SVRI and Paw were insignificant (p > 0.05).

Time → T0 ↓ Variables		T1	Changes t(P- Value)
PR	85.00 ± 14.28	84.93 + 15.15	0.903263
MAP	95.20 ± 14.55	89.47 + 16.84	0.02985
CVP	8.03 ± 4 .09	8.60 + 4.21	0.265479
CO	6.08 ± 1.61	5.38 +1.58	3.09 E -07
CI	3.74 ± 0.98	3.28 + 0.93	2.41 E -07
SV	70.33 ± 12.88	63.97 +11.05	0.001531
SVV	7.43 ± 2.28	14.40 +1.83	1.82 E -14
SVR	1235.57 ± 388.02	1238.40 +387.98	0.925618
SVRI	2010.83 ± 596.97	2008. 70 + 645.44	0.99344
Paw	23.97 ± 7.69	22.30 + 7.20	0.069236

Table 4: *Comparison of T_2 and T_3.*

Table 5 compares the values of variables at T_3 and T_4. C0, CI, SVV had highly significant value ($p < 0.001$). SV and SVR were significant ($p < 0.05$). PR, MAP, CVP, SVRI & Paw were insignificant. The p-value of SVV was the most significant (p value =1.49 E-13)

Time → T0 ↓ Variables		T1	Changes t(P- Value)
PR	84.93 ± 15.15	85.47 ± 15.00	0.508682
MAP	89.47 ± 16.84	91.60 ± 14.26	0.248595
CVP	8.60 ± 4.21	8.13 ± 3.71	0.40014
CO	5.38 ± 1.58	6.05 ± 1.62	2.87 E -05
CI	3.28 ± 0.93	3.73 ± 1.05	3.31 E -05
SV	63.97 ± 11.05	69.53 ± 11.97	0.001492
SVV	14.40 ± 1.83	7.43 ± 2.19	1.49 E -13
SVR	1238.40 ± 387.98	1154.03 ± 306.56	0.006682
SVRI	2008.70 ± 645.44	1881.17 ± 503.31	0.020126
Paw	22.30 ± 7.20	22.07 ± 7.21	0.517353

Table 5: *Comparison of T_3 and T_4.*

The following were the significant observations in this analysis:-

1. There were a total of 28 right thoracotomies and 2 left thoracotomies.
2. When the patient is turned lateral from supine position the changes in CVP, CI & PR were significant. The changes in CVP were more significant with a p-value of 0.001052. Other variables including SVV were insignificant.
3. After the chest is opened, PR, MAP, Paw and CVP were significant. The increase in PR and MAP can be attributed to stress response of incision. The mean value of CVP increased from 5.57 ± 2.78 to 8.03 ± 4.09 with a p-value of 0.003228 just on opening the chest. The CO, CI, SV, SVV do not show much variation.
4. After 500 ml of blood loss i.e. T_3 changes in CO, CI, SV, and SVV are highly significant with SVV being the most significant. Other variables do not show much variation.

5. At T_4 i.e. after replacement with 500 ml of volume, the mean SVV decreases from 14.40 ± 1.83 (at T_3) to 7.43 + 2.19 (at T_4) with a p-value of 1.49 E -13. CO, CI, SV are also significant but PR, MAP, CVP, Paw do not show much change.

Discussion

Measuring SVV has been shown to be useful in detecting fluid responsiveness in mechanically ventilated patients after cardiac surgery in closed-chest conditions. In the closed thorax, changes in intrathoracic pressure during each respiratory cycle cause predominantly cyclic changes in venous return, preload and SV. SVV has so far not been studied in detail under partially open-chest conditions with changes in preload volume. The present study indicates that heart-lung interactions caused by positive-pressure ventilation can be quantified by SVV during one lung ventilation, and that SVV is predictive of fluid responsiveness.

After the chest is opened, PR, MAP, Paw and CVP show significant changes. The changes in PR, MAP could be due to the stress response to surgical incision and changes in Paw are due to variable lung inflation but the changes in CVP are difficult to explain. It has been shown that during thoracic and cardiac surgeries, CVP is not suitable for monitoring fluid status. As demonstrated by earlier workers, filling pressures i.e. CVP might not be the monitoring parameter of choice under open chest conditions. CVP depends not only on intravascular volume and peripheral vessel tone but also on right and left ventricular compliance, pulmonary vessel resistance and intrathoracic pressure. [1]

In our study after 500 ml of blood loss, changes in CO, CI, SV and SVV are highly significant with SVV showing the most significant results i.e. values > 10% and a p-value of 1.82 E-14. After replacement with fluid, relative changes in SV, SVV, CO and CI were able to predict fluid responsiveness by showing normalization of values. Again SVV showed the maximum significance. According to our analysis PR, MAP, CVP did not show much change after 500ml blood loss. In the present study, no corelation was found between changes in PR, CVP and MAP before and after fluid loading.

We have found that FloTrac is a minimally invasive monitoring aid and provides continuous hemodynamic assessment. Other advantages include earlier identification of circulatory deficiencies that ultimately lead to shock, organ failure, and death. Values derived from traditional monitoring method such as blood pressure, heart rate, and oxygen saturation are not reliable predictors of mild hypovolemia. The speed and ease of setting up minimally invasive equipment allows clinicians to begin assessing patient's hemodynamic status and implementing effective treatment earlier than they can with a PAC. Earlier diagnosis of circulatory deficiency allows therapy to be initiated sooner, and less invasive monitoring may assist in the management of high risk surgical patients for whom invasive monitoring technologies are not an option.

SVV determined by minimally invasive monitoring has been used to guide fluid loading in patients undergoing cardiac surgery, neurosurgery, and vascular surgery and in those with severe sepsis. [2-9] In cardiac surgery patients, Preisman and colleagues used Pulse induced Contour Cardiac Output (PiCCO) and Transesophageal Doppler to monitor responses to consecutive volume loading with 250ml of colloid during and after surgery. [5] The Receiver Operating Characteristics (ROC) curves for SVV, SPV, and PP, were superior to those of MAP and CVP. Perner and colleagues demonstrated that SVV did not predict fluid responsiveness in patients with septic shock undergoing pressure support ventilation; however, this would be an expected response because pleural or transpulmonary pressure variation and positive pressure ventilation effect CO. [10] It should also be noted that SVV as measured by arterial pulse cardiac output (APCO) has thus far only been validated in patients exclusively receiving positive pressure ventilation. In our study, patients were on IPPV. Initial control values were when the chest was partially opened but there was no blood loss. Subsequent study values were done after blood loss of 500 ml and its replacement and the utility of functional hemodynamic monitoring was assessed. Baek et al found that more than half of a group of high-risk postoperative patients developed a decrease in CVP and PAOP in response to plasma volume expansion. [11]

With respect to practical use of SVV monitoring for guiding fluid therapy in clinical practice, the limitations of this method have to be emphasized in patients with abnormal cardiac rhythm. However, so far we have insufficient data to finally decide at which grade of arrhythmias functional preload indices can no longer be used to predict fluid responsiveness. SVV has recently been reported to become

a poor predictor of preload responsiveness in mechanically ventilated patients with severe arrhythmias.12 In our study an abnormal cardiac rhythm was included in exclusion criteria.

Both ventilatory issues (tidal volume, PEEP, chest and lung compliance) and cardiovascular issues (heart rate and rhythm, ventricular function, cardiac afterload, arterial compliance) may affect functional preload indices. How these factors influence these indices has to be known for correct interpretation of the values derived from the arterial pressure signal and real time continuous cardiac output devices. [13] While monitoring SV over time, alterations in ventilatory settings i.e. tidal volumes, level of positive end-expiratory pressure, respiratory rate with concomitantly increasing intrinsic positive end-expiratory pressure, intermittent spontaneous patient breathing, as well as the occurrence of dysrhythmias or alterations of myocardial contractility (including pharmacologic stimulation) may render these SVV estimates unreliable. Thus, mechanical ventilation in fully sedated patients, sinus rhythm, or pacing in a fixed mode and unchanged catecholamine management are prerequisites for proper use of this dynamic monitoring tool. [6]

In this study, it can be concluded that the SVV is the most sensitive indicator of fluid responsiveness during one lung ventilation with threshold value being around 10%. Out of all the variables, SVV co-related best with changes in CI associated with volume challenge. Thus assessing the hemodynamic consequences of ventilation induced heart lung interactions allows prediction of fluid responsiveness in patients undergoing surgical procedures with partially opened chest conditions desiring one-lung ventilation.

Summary and Conclusion

In summary, our results strengthen the importance of functional hemodynamic monitoring in one lung ventilation. During one lung ventilation, static parameters like CVP are not suitable for monitoring fluid status. Direct volume measurement with SVV is clearly superior to CVP in open chest conditions. The FloTrac sensor is easy to use, requiring only a standard arterial line and no external calibration to continuously calculate CO related data. SVV is shown to react more rapidly than changes in CVP when evaluating a patient's responsiveness to intravascular blood volume and preload. Additional fluid administration is usually essential when SVV exceeds 10%. In view of these findings, we believe that routine monitoring of SVV by a minimally invasive device is extremely useful in assessing fluid responsiveness in surgeries requiring one-lung ventilation.

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