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STROKE VOLUME VARIATION IS A GOOD PREDICTOR OF FLUID RESPONSIVENESS IN CARDIAC SURGERY PATIENTS WITH IMPLANTED INTRA-AORTIC BALLOON PUMP

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Abstract

There is a vast body of evidence in favour of individualising fluid therapy using dynamic hemodynamic indices like stroke volume variation (SVV). Patients with implanted intra-aortic balloon pump (IABP) are excluded from this approach because of pulse contour artifacts caused by the pump. The aim of this work is to test whether SVV can be used for fluid responsiveness prediction in these patients. Patients after cardiac surgery with implanted IABP were included in this study. SVV was measured after placing the IABP on standby mode for one minute. Cardiac output (CO) measurement was obtained via Swan-Ganz catheter before and after a 6 ml/kg fluid challenge. Fluid responsiveness was defined as increase of CO by at least 10%. SVV above 8.5% showed a good correlation with fluid responsiveness. Sensitivity was 95 (95% CI 85 to 100) and specificity 82 (95% CI 72 to 92). SVV had an area under the ROC curve 0.91 (95% CI 0.81 to 1.0) SVV is a good predictor of fluid responsiveness in patients with IABP. SVV should not be excluded as a fluid therapy guide for these patients. Placing the pump on standby for one minute allows obtaining an accurate measurement of this important variable.

Key words: stroke volume variation, fluid responsiveness, intra-aortic balloon pump

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Introduction. Fluid therapy during shock aims at optimization of CO and improvement of oxygen delivery to tissues. Using fluids has side effects like circulatory overload, pulmonary and tissue edema, dilutional coagulopathy and anemia. On the other hand, restricting fluid can result in complications like hypovolemia, tissue hypoperfusion and acute kidney injury. Evidence shows that roughly half of the critically ill are not responsive to fluids [1].

These facts led to intensive research of methods for prediction of fluid responsiveness. Vast body of evidence supports the use of cardiopulmonary interactions during mechanical ventilation [1]. Positive pressure ventilation causes cyclic changes in preload of right and left ventricles, which leads to respiratory stroke volume variation. That is actually a mini fluid challenge testing the position of the heart on the Frank–Starling curve. If the stroke volume varies significantly during breaths, this means that the heart is on the steep portion of the curve and is likely fluid responsive. If the SVV is low, the heart is probably on the flat portion of the curve and fluid bolus is unlikely to improve CO. Many patients do not meet the criteria for good fluid responsiveness prediction value of SVV: controlled mechanical ventilation with tidal volume of 8 ml/kg and regular heart rhythm. Actually practice in a cardiac surgical ICU offers a way around these obstacles. Patients are sedated and ventilated on admission, irregular heart rhythm can be overridden by pacing.

A more dated approach relies on the cardiac filling pressures like CVP or PCWP as a guide to fluid therapy. Trends in cardiac filling pressures have also been used for fluid responsiveness prediction. These indices have been widely criticized because of evidence for extremely poor predictive value for fluid responsiveness [1–3].

Fluid challenges remain popular because of their simplicity. A fluid bolus is infused and a change in CO is sought. Although tempting, fluid challenge is typically needed several times during the day for a patient in critical condition which leads to significantly positive fluid balance.

Scientific literature worldwide lacks data about the predictive value of SVV in patients with implanted IABP. It is commonly agreed that one of the conditions to use SVV for fluid therapy guidance is absence of IABP. That is because the pump generates pulse contour artifacts which prevent the currently available monitors from calculating SVV accurately. In our opinion this approach is correct, nevertheless it leaves us with the above listed options for fluid guidance and their pitfalls. We decided to try and avoid this inconvenience by simply putting the pump on standby for a brief period to be able to obtain a realistic SVV value.

IABP is essentially a balloon tipped catheter, which is introduced in the descending aorta. The device is pulsating synchronized with the cardiac cycle, the balloon is inflated during the cardiac diastole and is deflated during systole. As a result cardiac afterload is reduced and coronary perfusion pressure is increased. Intraoperative IABP placement is dictated by inability to separate the patient

from cardiopulmonary bypass [4]. These patients most often have severe cardiac dysfunction, severe inflammatory response syndrome, and their intravascular volume varies widely. That is why it is imperative to know which patients are fluid responsive.

The aim of this study is to test SVV as a predictor of fluid responsiveness in patients with IABP in the early postoperative period in the cardiac surgical ICU.

Materials and methods. Patients on the first day after cardiac surgery with intraoperatively implanted IABP were included in this study. The study has gained approval by the hospital ethics committee and informed consent has been obtained from every patient prior to inclusion. For the period of the study all patients in University Hospital "Sveta Ekaterina" were offered to participate in the study prior to their surgery.

Inclusion criteria were as follows:

- implanted IABP
- closed chest
- controlled mandatory mechanical ventilation
- regular heart rhythm
- no ECMO
- low cardiac output syndrome was defined as [4]:
  - cardiac index less than 2.2 L/min/m^2 or
  - lactate $>$ 3 mmol/L or
  - $ScvO_2$ below 50% (having $PaO_2 > 80$ mmHg) or
  - hypotension defined as systolic arterial pressure $<$ 90 mmHg or mean perfusion pressure $<$ 60 mmHg

Inclusion criteria were chosen in accordance with the available recommendations for SVV prediction validity for fluid responsiveness in other patient populations [3]. In addition, evidence for low cardiac output syndrome was sought as a reason to apply a therapeutic intervention like fluid loading.

All patients underwent elective or emergent surgery of the heart and great vessels. After administering intravenous induction tracheal intubation was performed and anaesthesia was maintained with a balanced approach using an inhalation and an intravenous agent.

Operation technique was standardized for all surgical teams and no equipment or medical consumables changes took place for the study period. Leading surgeon was a registered specialist in all cases. Venous grafts were obtained from the saphenous leg veins, internal thoracic arteries were used for arterial grafts.

After median sternotomy right atrium and ascending aorta were cannulated and cardiopulmonary bypass was instituted on 32 °C. Valvuloplasty included a ring insertion (mitral or tricuspid valve), valve replacement was done using mechanical or biologic prosthesis. Preparations for discontinuing CPB were made – target hematocrit above 25%, optimization of electrolyte levels, cardiac rhythm optimization (antiarrhytmics, pacing), hemostasis of major bleeding, normothermia, catecholamine infusion started during reperfusion, etc. Thereafter CPB was gradually discontinued.

IABP was implanted intraoperatively due to inability to separate patients from cardiopulmonary bypass. Hospital protocol states that IABP should be chosen if there is evidence for low cardiac output syndrome after adequate fluid resuscitation and in addition to catecholamine index above 15. Catecholamine index = dopamine dose + noradrenaline dose * 100 + adrenaline dose * 100 + dobutamine dose (µg/kg/min)

A five lumen Swan–Ganz pulmonary artery catheter (Edwards Lifesciences 7.5 F 110 cm) for pulmonary artery thermodilution was inserted intraoperatively in all patients in accordance to IABP hospital protocol.

After surgery patients were admitted to the cardiac surgical ICU for monitoring and status optimization. All patients were sedated and ventilated. They all had pressure triggered IABP put on 1:1 mode.

Monitoring included continuous ECG, invasive and noninvasive arterial pressure, CVP, Edwards Lifesciences Swan–Ganz catheter with invasive pulmonary artery pressure and CO measurements, pulse oximetry, ABGs, hourly diuresis measurements, hourly surgical drains output measurements and laboratory testing. Edwards Lifesciences Vigileo™ monitor and FloTrac™ sensor were attached to the arterial cannula for SVV measurement.

The algorithm used for hemodynamic measurements was as follows:

1. IABP was switched from 1:1 to standby mode for one minute.
2. SVV value was obtained.
3. IABP was switched back to 1:1 mode.
4. CO was measured using the S.G. catheter (after IABP 1:1 for 5 min).
5. Fluid bolus of 6 ml/kg Gelafusine was infused for 10 min via infusion pump.
6. CO was measured again after 5 min.

The IABP machine generates cyclic changes in the aortic blood pressure. Balloon inflation right after aortic valve closure raises aortic diastolic pressure and balloon deflation before aortic valve opening results in reduced cardiac afterload.

Aortic pressure changes caused by the pump prevent the currently available software to measure SVV accurately. In order to avoid false measurements we choose to put the IABP on pause for one minute.

FloTrac™ sensor was connected to Vigileo™ monitor (Edwards Lifesciences) programmed with 1.07 software version. SVV is calculated by the Vigileo™ monitor software based on pulse contour analysis using the equation

$$\text{SVV } (\%) = (\text{SV}_{\max} - \text{SV}_{\min})/\text{SV}_{\text{mean}}. \tag{1}$$

The monitor uses 20-second intervals of the arterial pressure curve for calculation [5]. That means that placing the pump on standby for one minute is more than enough for accurate measurement of SVV. Prior to SVV assessment tidal volume on the ventilator was adjusted to 8–10 ml/kg in accordance with available recommendations [3].

Position of the S.G. catheter in the pulmonary artery was confirmed via PA pressure waveform, test-wedging and chest X-ray. Cardiac output was measured in accordance with Edwards Lifesciences recommendations. None of the patients had high degree tricuspid valve regurgitation, patients were all warmed to 37 °C using a bear hugger and 10 ml 0.9% NaCl solution at room temperature was injected in the proximal lumen of the catheter. Three consecutive measurements were made and a mean value was calculated. Measurements with poor quality of the thermodilution curve were excluded. IABP was on during the CO measurements as the pump was working continuously and it was crucial to obtain a value of the CO relevant to the patient's condition. IABP function does not interfere with CO measurement via a S.G. catheter [6].

To avoid theoretical danger of acute hemodynamic decompensation while the IABP is on pause arterial pressure was closely monitored. We decided that if mean arterial pressure dropped under 65 mmHg or by more than 20% of base value if initially under 65 mmHg, IABP was to be put back to 1:1 mode. None of the participating patients experienced such hemodynamic changes.

Measures were taken to avoid circulatory overload due to the fluid challenge. Central venous pressure and arterial pressure values were closely monitored. If CVP raised over 20 mmHg or mean arterial pressure dropped under 65 mmHg (or by more than 20% if base value was under 65 mmHg) fluid infusion was to be stopped immediately. Such hemodynamic changes occurred in none of the included patients.

Data analysis. Acquired data was analyzed using IBM SPSS 25. Hemodynamic parameters before and after fluid challenge were compared using Student's paired t-test. Fluid responsiveness predictive value of SVV was tested using a ROC curve for improvement of CO by 10% or more. Threshold predictive value of SVV was chosen as the value with highest sensitivity and specificity.

Results. In the period August 2018 – August 2019, 761 cardiac operations with cardiopulmonary bypass (CPB) were performed in University Hospital

"Sveta Ekaterina". During that period 35 consecutive cases of intraoperative IABP implantation were enrolled in the study. Five of them were excluded due to co-implantation of ECMO. All other 30 patients met the study inclusion criteria. The study group represents 3.9% of all patients operated on CPB in the hospital for the selected time interval.

Low cardiac output syndrome was diagnosed in all 30 patients. Lactate level was above 3 mmol/L in 63% of the patients, $ScvO_2$ was below 50% in 33% ($PaO_2 >$ 80 mmHg). Mean perfusion pressure (MPP) was below 60 in 23% of the cases and systolic arterial pressure (SAP) was below 90 in 3%. Cardiac index was below 2.2 L/min/m^2 in 60% of the patients.

Thirty patients ASA class 3 or 4 were included in this study: 18 males, 12 females, male/female ratio 1.5, age 67.9 ± 8.3, weight 80.3 ± 14.3 kg, height 166.4 ± 9.7 cm, BMI 27.9 ± 4.9. Ejection fraction $40.7 \pm 14.5\%$, Euroscore $22.8 \pm$ 19.3%, hypokinetic left ventricle preoperatively – 70% of patients, left ventricle hypertrophy – 40% of patients.

Mean operation duration time was 308 min, mean cardiopulmonary bypass (CPB) time was 115 min, mean aortic cross-clamp time – 57 min, mean catecholamine index – 16.3 (Table 1).

Table 1

Intraoperative patient characteristics

	Mean	SD
Operation duration time in minutes	308	47.4
CPB time in minutes	115	35.7
Aortic crossclamp time in minutes	57	23.4
Catecholamine index	16.3	14

Type of surgery was distributed as follows: combined operation (revascularization and valve surgery) – 40%, revascularization – 40%, valve surgery – 16.7%, pulmonary artery thrombectomy – 3.3%.

Initial measurements of the study group hemodynamics showed means of HR 96.2 ± 9.9, SAP 106.8 ± 12.4 mmHg, MAP 78.3 ± 11.8 mmHg, MPP $70.5 \pm$ 12.3 mmHg, CVP 7.9 ± 3.9 mmHg, PCWP 13.0 ± 4.5 mmHg, PAM $22.6 \pm$ 7.6 mmHg. Mean SVV was 11.8 ± 5.7, mean CI before fluid challenge was 2.0 ± 0.8 L/min and after – 2.3 ± 0.9 L/min.

Nineteen patients were identified as fluid responders and eleven as fluid non responders; fluid responsiveness rate was 63.3% in the study group. Figure 1 shows CO before and after fluid challenge in the whole group, the fluid responding group and fluid nonresponding group.

Based on the acquired data a ROC curve of SVV as a predictor of fluid responsiveness was obtained. Fluid responsiveness was defined as an increase of

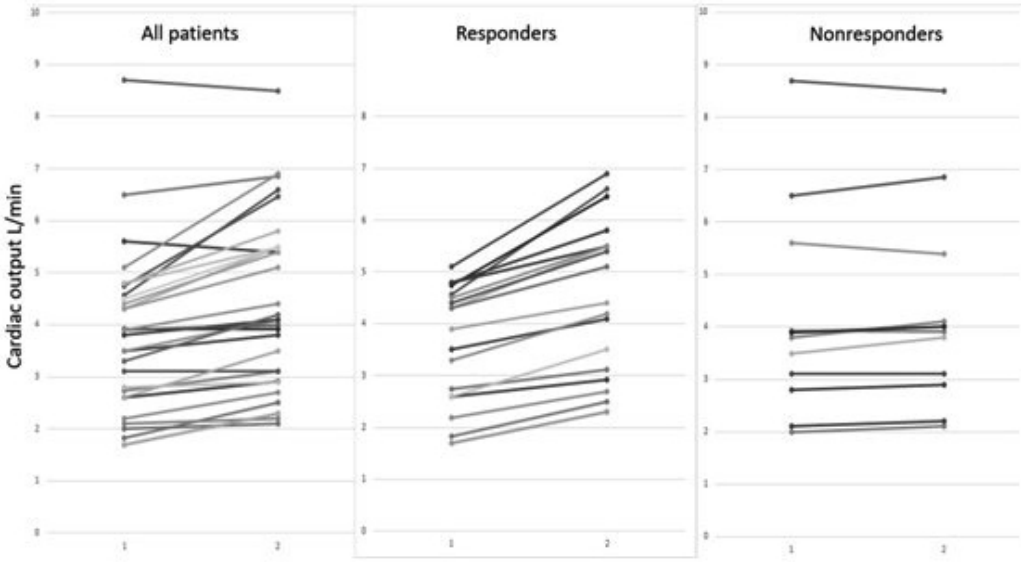


Fig. 1. Cardiac output before and after fluid challenge

SVV %	dCO %
13	44,74
21	36,61
4	23,29
17	27,91
10	5,38
15	13,50
7	-0,26
6	-3,57
12	35,29
16	36,00
10	12,31
8	8,57
13	5,00
15	35,29
18	22,73
13	14,58
28	17,14
9	18,60
4	7,89
6	2,56
17	27,27
3	4,76
8	0,00
7	-2,30
9	12,82
12	34,62
6	3,57
16	22,22
15	35,29
17	20,83

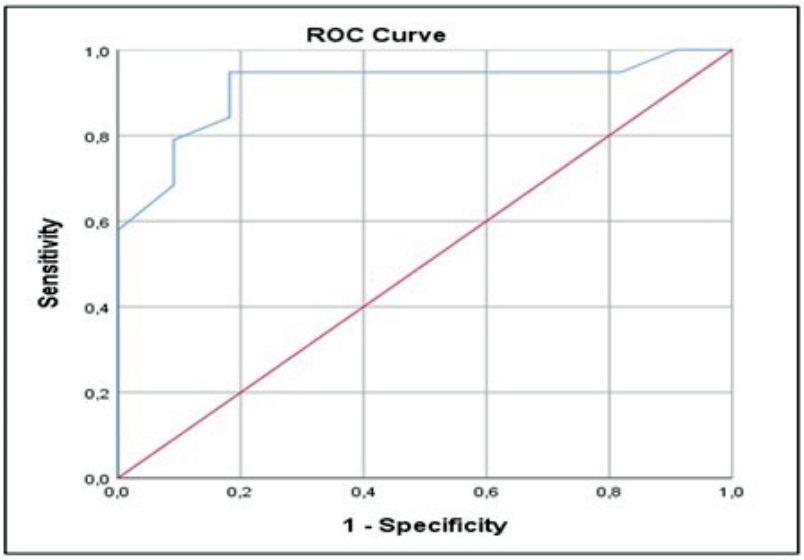


Fig. 2. ROC Curve of SVV predictive value for fluid responsiveness dCO – change in cardiac output before and after fluid challenge

CO by 10% or more. The following parameters of the ROC curve were calculated: AUC 0.91 (95% CI 0.8–1.0), Std. error 0.055, Sig. 0.0002 (Fig. 2).

SVV of 8.5% showed the highest additive value of sensitivity and specificity and was identified as best threshold value. Sensitivity for that value was 95 (95% CI 85–100) and specificity – 82 (95% CI 72–92).

Discussion. The present study challenges the belief that IABP is a contraindication for using SVV for fluid responsiveness prediction. Although strictly speaking that is correct we sought a way to go around that obstacle by putting the pump on standby for one minute. We tested that method by measuring the cardiac output via S.G. catheter before and after fluid challenge and obtained promising results. We feel obliged to share this methodology that works in our clinic with the critical care community.

Predicting fluid responsiveness using SVV by the bedside is easy, cheap and relatively noninvasive. We think that in daily routine that can be done without measuring the cardiac output. The need for hemodynamic optimization should be dictated by evidence for tissue hypoperfusion.

The Vigileo/FloTrac system is an uncallibrated monitor for pulse contour analysis [7]. Calculation of stroke volume is actually area under the curve multiplied by a constant. "Stroke volume variation" is a variable independent from the actual stroke volume. If the devise calculates stroke volume that is inaccurate, the same mistake would be applied to all other stroke volume calculations. Therefore the variation between calculated stroke volumes is accurate.

The conducted study confirms that SVV is a good predictor of fluid responsiveness. This is the first time patients with IABP are included in such study. The presented data show that placing the pump on standby for one minute is a valid way to obtain an accurate SVV value. That allows this group of patients to benefit from an individualized approach to fluid resuscitation with potential reduction of morbidity and mortality. The presented study is the first one to focus on dynamic hemodynamic indices during fluid resuscitation in Bulgaria.

SVV values of 8.5% or above showed a very good predictive value for fluid responsiveness in the studied group. Using SVV to guide fluid therapy has the potential to reduce circulatory overload complications like pulmonary edema, ileus, etc. It is also possible to avoid tissue hypoperfusion by giving the right amount of fluids.

Interpretation of dynamic hemodynamic variables like SVV, pulse pressure variation, systolic pressure variation, and so on, must be cautious and should take into account some important considerations. These variables are generally good predictors of fluid responsiveness but they cannot be an indication for fluid loading. Respiratory variation of stroke volume or pulse pressure is a normal state of the circulation. A healthy volunteer would have a SVV of 10–15%. That means that they are likely fluid responsive but this does not indicate that they need fluids. The need for fluid loading is dictated by signs of tissue hypoperfusion such as lactatemia or low $ScvO_2$. Initial enthusiasm for the use of dynamic hemodynamic indices tempted many clinicians to infuse too much and too often. It must be recognized that significantly positive fluid balance is an independent risk factor for increased morbidity and mortality [8]. Sometimes it is in the patient's best interest to avoid fluids and increase inotropic support instead. A low value of SVV is a very good reason to restrict fluid administration.

Our experimental data show that 63% of the IABP patients are fluid responsive, which is a significant scientific contribution. No other studies are focused on fluid responsiveness rate in patients with IABP. Having in mind that many clinicians do not have access to monitors for SVV or surrogate variables, empirical fluid loading would result in successful resuscitation in 63% of the cases. This is valuable information because very often patients with IABP are already on very high inotropic support and increasing the catecholamine infusion further could result in supply demand mismatch and myocardial ischemia.

The presented results are promising and suggest that such approach to fluid therapy could be used also intraoperatively after closing of the chest when hemodynamic collapse frequently occurs.

The present study has important limitations related to the small amount of participants – 30 patients. However, on review of the literature it becomes evident that the majority of studies focused on fluid responsiveness include approximately the same amount of patients. The presented data suggest SVV of 8.5% as best threshold value for predicting a positive response to fluids. Typically in the general ICU population SVV threshold is thought to be 10–13% depending on authors [9]. A sudden stop of the IABP changes the hemodynamics unfavourably for the heart. It may be the case that the SVV variation measured during IABP on standby is actually higher when the pump is working. However, as mentioned above, the currently available monitors are unable to measure SVV accurately during counterpulsation. The aforementioned threshold differences may be due to unique characteristics of the study group such as high catecholamine index, altered vascular tone, etc. Further research is needed to determine whether SVV of 8.5% is actually the best threshold value for the group of interest.

Conclusion. Respiratory variation of stroke volume is probably a good and reliable predictor of fluid responsiveness in patients with implanted IABP. Placing the pump on standby for a brief period could easily be used by many clinicians working with these patients. Most certainly an individual approach to hemodynamics is needed for the complicated cardiac surgery patient.

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