Evaluation of radial artery pulse pressure effects on detection of stroke volume changes after volume loading maneuvers in cardiac surgical patients

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Background: Fluid responsiveness is defined as an increase in cardiac output (CO) or stroke volume (SV) of >10–15% after fluid challenge (FC). However, CO or SV monitoring is often not available in clinical practice. The aim of this study was to evaluate whether changes in radial artery pulse pressure (rPP) induced by FC or passive leg raising (PLR) correlates with changes in SV in patients after cardiac surgery.

Methods: This prospective observational study included 102 patients undergoing cardiac surgery, in which rPP and SV were recorded before and immediately after a PLR test and FC with 250 mL of Gelofusine for 10 min. SV was measured using pulse contour analysis. Patients were divided into responders (≥15% increase in SV after FC) and non-responders. The hemodynamic variables between responders and non-responders were analyzed to assess the ability of rPP to track SV changes.

Results: A total of 52% patients were fluid responders in this study. An rPP increase induced by FC was significantly correlated with SV changes after a FC (ΔSV-FC, r=0.62, P<0.01). A fluid-induced increase in rPP (ΔrPP-FC) of >16% detected a fluid-induced increase in SV of >15%, with a sensitivity of 91% and a specificity of 73%. The area under the receiver operating characteristic curve (AUROC) for the fluid-induced changes in rPP identified fluid responsiveness was 0.881 (95% CI: 0.802–0.937). A grey zone of 16–34% included 30% of patients for ΔrPP-FC. The ΔrPP-PLR was weakly correlated with ΔSV-FC (r=0.30, P<0.01). An increase in rPP induced by PLR (ΔrPP-PLR) predicted fluid responsiveness with an AUROC of 0.734 (95% CI: 0.637–0.816). A grey zone of 10–23% included 52% of patients for ΔrPP-PLR.

Conclusions: Changes in rPP might be used to detect changes in SV via FC in mechanically ventilated patients after cardiac surgery. In contrast, changes in rPP induced by PLR are unreliable predictors of fluid responsiveness.

Keywords: Radial pulse pressure; fluid responsiveness; fluid challenge (FC); passive leg raising (PLR); stroke volume (SV)

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Introduction

Appropriate fluid resuscitation is the most important hemodynamic intervention in the early postoperative period in patients after cardiac surgery (1,2). However, the risk of fluid overload has been clearly established, especially in patients with a limited cardiac reserve. For this reason, it is important to know whether the patient will respond to volume expansion (VE) before fluid administration (3,4). Several indicators and tests are currently available to identify fluid responsiveness to avoid deleterious fluid overload (2-7). The percentage change in cardiac output (CO) or stroke volume (SV) following fluid challenge (FC) has been used to discriminate responders from non-responders (8-10). However, direct CO or SV measurements are not available in most critically ill patients in routine clinical practice (11,12). Consequently, alternative hemodynamic variables such as changes in arterial pressure are still frequently used to assess FC response in clinical practice (12). Because pulse pressure (PP) is physiologically related to SV, some authors have reported using the changes in PP as a surrogate parameter of the changes in SV after a FC (12-17). However, these studies were mainly conducted in septic shock patients. Whether PP can effectively be used to discriminate fluid responsiveness compared to SV has not been well demonstrated in patients after cardiac surgery. The aim of the present study was to document the relationship between SV and radial artery pulse pressure (rPP) after passive leg raising (PLR) and FC in mechanically ventilated patients after cardiac surgery.

We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/atm-20-847).

Methods

Patients

This prospective single-center observational study was conducted in a 39-bed cardiac surgery intensive care unit (CSICU) of Zhongshan Hospital, Fudan University (Shanghai, China). Patients were enrolled in a consecutive nonrandomized manner between April 1 and July 30, 2019. Approval was obtained from the Ethics Committee of Zhongshan Hospital (No. B2016-077) and informed consent was obtained from all study patients.

All patients were routinely undergoing transesophageal echocardiography to detect or quantify cardiac disorders as well as to confirm the effect of surgery immediately after the procedure. After admittance to the CSICU and before study enrollment, patients were also routinely undergoing transthoracic echocardiography to identify different causes of hypotension, such as hypovolemia, heart failure, cardiac tamponade, and tension pneumothorax. The decision to perform VE was based on the clinical judgment of the intensivists. Indeed, the decision to FC was made individually on the basis of hemodynamic instability or signs of inadequate tissue perfusion. Hemodynamic instability was principally based on hemodynamic parameters and laboratory examinations, including at least one of the following criteria: systolic arterial pressure (SAP) <90 mmHg (or a decrease of >50 mmHg in patients previously known as hypertensive), mean arterial pressure (MAP) <65 mmHg, or the need for vasopressor infusion, urinary output of ≤0.5 mL/kg/h for at least 2 h, blood lactate of >2 mmol/L, or presence of skin mottling. Patients with active bleeding, arrhythmia, right heart dysfunction (tricuspid annular plane systolic excursion <16 mm), intracardiac shunt, and pulmonary hypertension were excluded in this study.

Management

All patients had a central venous catheter and a radial arterial catheter, which were routinely placed in the operating room. FloTrac/Vigileo system (Edwards Lifesciences, Irvine, CA, USA) was then connected to the radial arterial catheter. SV, CO, and stroke volume variation (SVV) were acquired from the FloTrac/Vigileo system. Pressure transducers were consistently adjusted to the level of the patient's right atrium. Standard postoperative cardiac patient monitoring characteristics included continuous electrocardiography, heart rate (HR), pulse oximetry (SpO_2), central venous pressure (CVP), and invasive radial arterial blood pressure. SAP, diastolic arterial pressure (DAP), and MAP were recorded from the bedside monitor connected to the FloTrac/Vigileo pressure transducer. All patients received remifentanil and propofol to achieve deep sedation and were mechanically ventilated without spontaneous breathing. The ventilator settings were adjusted according to routine practice. These criteria included mechanical ventilation mode: intermittent positive pressure ventilation, tidal volume: 6 and 8 mL/kg of ideal body weight, respiratory rate: 15 breaths per min, FiO_2: 50%, plateau pressure <30 cmH_2O, $PaCO_2$ ≤45 mmHg, and SpO_2 >95% (5,6). Since higher PEEP may have adverse effects, such as lung over inflation and hemodynamic deterioration, a

PEEP of 5 cmH_2O was set initially after cardiac surgery.

Study design

Three set of measurements, including HR, SAP, DAP, MAP, rPP, CVP, SVV, CO, and SV, were recorded at baseline, at the end of PLR, and after a FC (250 mL of Gelofusine for 10 min). The patient was placed in a semi-recumbent position (45°) at baseline. Thereafter, a standardized PLR test was performed as previously described (18,19). Briefly, the patient was moved from the semi-recumbent position to a position in which the legs were elevated to 45° and the trunk remained horizontal. This was achieved by moving the bed without touching the patient. The body posture was then returned to the baseline position. A FC was carried out after SV was stable. Infusion rates of vasopressors, inotropic agents, and sedative drugs were kept consistent during the study periods.

Changes (in %) in rPP induced by PLR (ΔrPP-PLR) and FC (ΔrPP-FC) were expressed as relative changes [(rPP after PLR minus rPP at baseline)/rPP at baseline; (rPP after FC minus rPP at baseline)/rPP at baseline]. Changes (in %) in SV induced by PLR and FC were expressed as relative changes [(SV after PLR minus SV at baseline)/SV at baseline, (SV after FC minus SV at baseline)/SV at baseline].

Statistical analysis

Results were expressed as means ± standard deviation (SD) for quantitative variables and frequencies with percentages for qualitative variables according to variable distributions. Data comparison between fluid responders and non-responders was performed using a two-sample Student's *t*-test. Comparisons within groups were assessed using Student's paired *t*-test. Analysis of categorical data utilized the χ^2 or Fisher's exact methods. Patients were divided into two groups according to the SV increase of >15% after FC (20). The receiver operating characteristic (ROC) curves were used to evaluate the discriminative power of ΔrPP-PLR (%), ΔrPP-FC (%), ΔSAP-PLR (%), ΔSAP-FC (%), ΔDAP-PLR (%), ΔDAP-FC (%), ΔMAP-PLR (%), ΔMAP-FC (%), and SVVbaseline (%) as indicators to assess fluid responsiveness. The comparison of areas under the ROC curves was performed as previously described by DeLong *et al.* (21). The best cut-off value for each indicator was calculated by maximizing the Youden index (sensitivity + specificity − 1). Pearson's correlation coefficient was calculated to evaluate the correlation between different hemodynamic parameters. Statistical significance was defined as P<0.05. Statistical analysis was performed with SPSS software (version 19.0; SPSS, Inc., Chicago, IL, USA).

A grey zone approach was used to determine a range of values for which formal conclusive information could not be obtained. Grey zones were calculated according to the Cannesson method (22).

Results

Study population

A total of 102 patients (75 males) after cardiac surgery were included during the study period. Their basal and clinical data are summarized in *Table 1*. All patients were sedated without spontaneous breathing or cardiac arrhythmia. No patient exhibited right heart failure at echocardiography. A total of 52% patients were fluid responders defined by an increase in the SV of ≥15% after a FC. There was no statistical difference in baseline characteristics between the two groups.

Hemodynamic changes after PLR and FC

Hemodynamic data in responders and non-responders at all study times [baseline (T0), PLR (T1), and FC (T2)] are reported in *Table 2*. Basal HR was not different between the responders and non-responders (73±20 *vs.* 69±18 beats/min, P>0.05). A significant increase was present after PLR or FC for SAP (T1 122±20 *vs.* 100±16 mmHg, P<0.05; T2 125±21 *vs.* 100±16 mmHg, P<0.05), DAP (T1 63±12 *vs.* 55±12 mmHg, P<0.05; T2 62±11 *vs.* 55±12 mmHg, P<0.05), and MAP (T1 81±15 *vs.* 67±15 mmHg, P<0.05; T2 82±14 *vs.* 67±15 mmHg, P<0.05) in responders, whereas an increase was less apparent in non-responders. The CVP was increased in both groups from baseline to PLR or FC. In responders, PLR or FC significantly increased the rPP (T1 55±15 *vs.* 46±12 mmHg, P<0.05; T2 63±17 *vs.* 46±12 mmHg, P<0.05), CO (T1 3.5±1.6 *vs.* 2.9±1.2 L/min, P<0.05; T2 4.0±1.8 *vs.* 2.9±1.2 L/min, P<0.05), and SV (T1 48.8±15.2 *vs.* 40.4±11.1 mL, P<0.05; T2 55.0±16.9 *vs.* 40.4±11.1 mL, P<0.05) and decreased the SVV (T1 8±5 *vs.* 15±4, P<0.05; T2 8±4 *vs.* 15±4, P<0.05). The changes were less notable in non-responders.

Evaluation of changes in rPP and detection of changes in SV

No statistically significant correlations were present

Table 1 Main characteristics of responders and non-responders

Characteristics	Responders (n=53)	Non-responders (n=49)	P value
Age (yrs)	62±10	62±8	0.93
Sex, male/female, n (%)	40/13 (75.5/24.5)	35/14 (71.4/28.6)	0.64
Body Mass Index (kg/m^2)	23.6±3.2	23.7±3.1	0.87
Ideal body weight (kg)	61.6±8.4	60.3±7.8	0.42
EuroSCORE	4±2	3±2	0.25
APACHE II score	8±4	8±4	0.64
LVEF (%)	60±8	61±8	0.69
VT/IBW (mL/kg)	7.9±0.6	8.1±0.7	0.51
VT (mL)	490±51	484±45	0.57
RR (cycles/min)	15±0	15±1	0.54
$PaCO_2$ (mmHg)	39.9±4.9	38.7±4.2	0.19
PEEP (cmH_2O)	5	5	1.00
PaO_2/FiO_2 (mmHg)	365.5±144.2	420.3±178.8	0.09
Lactate (mmol/L)	1.6±2.1	1.6±2.2	0.96
Hemoglobin (dg/L)	12.5±11.8	11.4±2.1	0.53
Patients receive vasoactive agents, n (%)			0.06
Norepinephrine	20 (37.7)	21 (42.9)	
Dobutamine	0 (0.0)	3 (6.1)	
Norepinephrine plus dobutamine	6 (11.3)	10 (20.4)	
Dose of norepinephrine (μg kg^{-1} min^{-1})	0.04 (0.01–0.33)	0.04 (0.01–0.23)	0.85
Dose of dobutamine (μg kg^{-1} min^{-1})	0.5 (0.2–1.6)	0.75 (0.3–1.7)	0.48
Cardiac surgery category, n (%)			0.94
Valve	11 (20.8)	10 (20.4)	
CABG	35 (66.0)	34 (69.4)	
Aortic surgery	5 (9.4)	3 (6.1)	
Others	2 (3.8)	2 (4.1)	
Post-operative day of inclusion, n (%)			0.88
Day 0	47 (88.7)	43 (87.8)	
Day 1	6 (11.3)	6 (12.2)	

Values are expressed as the mean ± SD, median (25–75% inter-quartile range), or number and frequency in %. EUROScore, European system for cardiac operative risk evaluation; APACHE II, acute physiology and chronic health evaluation; LVEF, left ventricular ejection fraction; VT, tidal volume; IBW, ideal body weight; PEEP, positive end-expiratory pressure; $PaCO_2$, arterial partial pressure of carbon dioxide; PaO_2, arterial partial pressure of oxygen; FiO_2, inspiratory fraction of oxygen; CABG, coronary artery bypass grafting.

Table 2 Hemodynamic parameters measured in responders and non-responders

Variable	Baseline (T0)	After PLR (T1)	After FC (T2)
HR (bpm)			
Responders	73±20	72±19	71±18
Non-responders	69±18	68±17	68±17
SAP (mmHg)			
Responders	100±16	122±20*	125±21†
Non-responders	111±19‡	120±15*	120±22†
DAP (mmHg)			
Responders	55±12	63±12*	62±11†
Non-responders	58±10	61±12*	61±12†
rPP (mmHg)			
Responders	46±12	55±15*	63±17†
Non-responders	53±14‡	60±15*	59±16†
ΔrPP (%)			
Responders	–	21.9±12.6	38.6±21.3
Non-responders	–	12.4±9.2‡	9.2±15.7‡
MAP (mmHg)			
Responders	67±15	81±15*	82±14†
Non-responders	74±13‡	80±11*	80±15†
CVP (mmHg)			
Responders	8±4	11±4*	10±5†
Non-responders	9±4	12±4*	10±4†
CO (L/min)			
Responders	2.9±1.2	3.5±1.6*	4.0±1.8†
Non-responders	3.2±1.0	3.5±1.2*	3.4±1.1†
SV (mL)			
Responders	40.4±11.1	48.8±15.2*	55.0±16.9†
Non-responders	47.8±11.0‡	52.3±14.6*	50.6±12.3†
SVV (%)			
Responders	15±4	8±5*	8±4†
Non-responders	9±3‡	7±4*	7±4†‡

Values are expressed as the mean ± SD. *, P<0.05 baseline *vs*. after PLR, †, P<0.05 baseline *vs*. after FC; ‡, P<0.05 non-responders *vs.* responders. PLR, passive leg raising; FC, fluid challenge; HR, heart rate; SAP, systolic arterial pressure; DAP, diastolic arterial pressure; rPP, SAP minus DAP; ΔrPP, (rPP after PLR or FC minus rPP at baseline)/rPP at baseline; MAP, mean arterial pressure; CVP, central venous pressure; CO, cardiac output; SV, stroke volume; SVV, respiratory variation of stroke volume.

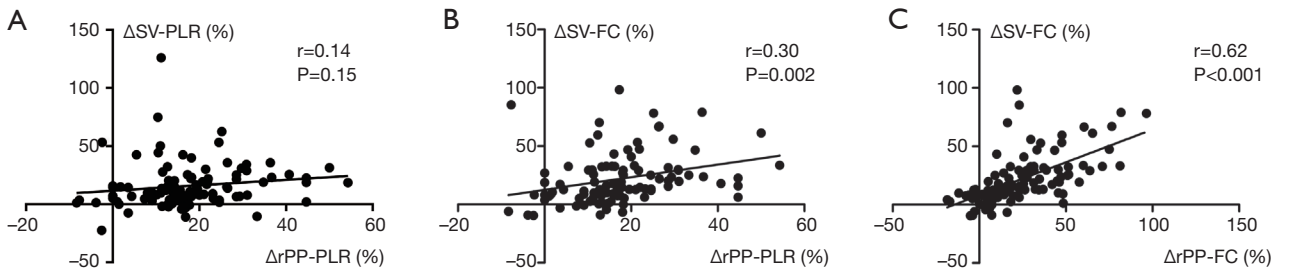

Figure 1 Pearson's correlation analysis. Relationship between (A) ΔrPP-PLR (%) and ΔSV-PLR (%); (B) ΔrPP-PLR (%) and ΔSV-FC (%); (C) ΔrPP-FC (%) and ΔSV-FC (%). PLR, passive leg raising; FC, fluid challenge; ΔrPP-PLR (%), changes in radial artery pulse pressure induced by PLR; ΔrPP-FC (%), changes in radial artery pulse pressure induced by FC; ΔSV-PLR (%), changes in stroke volume induced by PLR; ΔSV-FC (%), changes in stroke volume induced by FC; r, Pearson correlation coefficient.

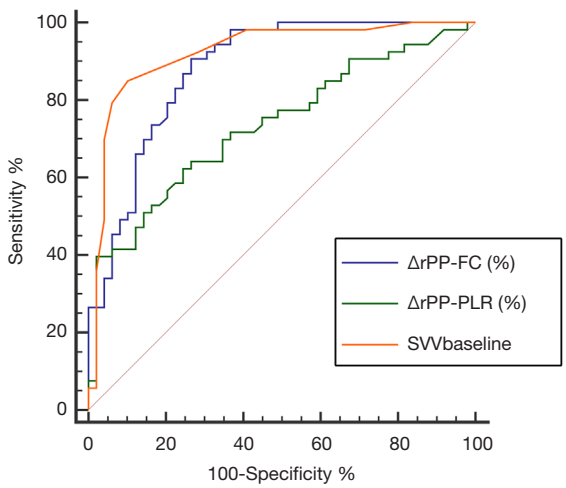

Figure 2 ROC curves generated for SVV at baseline, ΔrPP-PLR, and ΔrPP-FC show the effect of fluid challenge. ROC, receiver operating characteristics; SVV, stroke volume variation; PLR, passive leg raising; ΔrPP-PLR (%), changes in radial artery pulse pressure induced by PLR; ΔrPP-FC (%), changes in radial artery pulse pressure induced by FC.

between changes (in %) in rPP and changes (in %) in SV after PLR (ΔSV-PLR, *Figure 1A*, r=0.14, P=0.15). A weak relationship between changes (in %) in rPP after PLR and changes (in %) in SV after FC was also found (r=0.30, P<0.01, *Figure 1B*). The area under the receiver operating characteristic curve (AUROC) for the changes (in %) in rPP after PLR to predict fluid responsiveness was 0.734 (95% CI: 0.637–0.816, P<0.01). However, changes (in %) in rPP after FC had a significant positive correlation with changes (in %) in SV (r=0.62, P<0.001, *Figure 1C*). The AUROC for the changes (in %) in rPP after FC to detect a fluid-induced increase in SV of ≥15% was 0.881 (95% CI: 0.802–0.937, P<0.001, *Figure 2*).

The ability of radial arterial pressure changes to detect a fluid-induced increase in SV of >15% is described in *Table 3*. The AUROCs for the changes (in %) in SAP, DAP, and MAP after FC to detect a fluid-induced increase in SV of ≥15% were 0.778 (95% CI: 0.685–0.854, P<0.001), 0.684 (95% CI: 0.585–0.773, P<0.001), and 0.734 (95% CI: 0.638–0.817, P<0.001). The AUROCs for the changes (in %) in SAP, DAP, and MAP after PLR to predict fluid responsiveness were 0.754 (95% CI: 0.659–0.834, P<0.001), 0.652 (95% CI: 0.551–0.744, P<0.001), and 0.704 (95% CI: 0.605–0.790, P<0.001). The best cut-off values when detecting fluid responsiveness were >17% for rPP-PLR (sensitivity of 62.26% and specificity of 75.51%) and >16% for rPP-FC (sensitivity of 90.57% and specificity of 73.47%).

Grey zone limits

Inconclusive zone limits for SVV, ΔrPP-PLR, and ΔrPP-FC are represented in *Figure 3*. A large grey zone was found in ΔrPP-PLR and 43.9% of the patients were within this inconclusive zone. Conversely, small grey zones were observed in ΔrPP-FC and SVV, which included 30.39% and 4.9% of the patients, respectively (*Figure 3*).

Discussion

The objective of this study was to evaluate whether the changes in rPP can track the changes in SV after PLR or FC in mechanically ventilated patients after cardiac surgery. The present study showed that the changes in rPP

Table 3 Comparison of ability to assess fluid responsiveness

Parameters	Optimal cutoff	AUC (95% CI)	Sensitivity (%)	Specificity (%)	Youden index	Positive predictive value (95% CI)	Negative predictive value (95% CI)
ΔrPP-FC (%)	>16	0.881 (0.802–0.937)	90.57	73.47	0.640	3.41 (2.1–5.5)	0.13 (0.05–0.3)
ΔrPP-PLR (%)	>17	0.734 (0.637–0.816)	62.26	75.51	0.378	2.54 (1.5–4.3)	0.50 (0.3–0.7)
ΔSAP-FC (%)	>9	0.778 (0.685–0.854)	83.02	61.22	0.442	2.14 (1.5–3.1)	0.28 (0.1–0.5)
ΔSAP-PLR (%)	>21	0.754 (0.659–0.834)	58.49	87.76	0.463	4.78 (2.2–10.5)	0.47 (0.3–0.7)
ΔDAP-FC (%)	>4	0.684 (0.585–0.773)	67.92	71.43	0.394	2.38 (1.5–3.8)	0.45 (0.3–0.7)
ΔDAP-PLR (%)	>4	0.652 (0.551–0.744)	79.25	48.98	0.282	1.55 (1.1–2.1)	0.42 (0.2–0.8)
ΔMAP-FC (%)	>10	0.734 (0.638–0.817)	69.81	77.55	0.474	3.11 (1.8–5.4)	0.39 (0.3–0.6)
ΔMAP-PLR (%)	>7	0.704 (0.605–0.790)	83.02	53.06	0.361	1.77 (1.3–2.4)	0.32 (0.2–0.6)

AUC, area under the receiver operating characteristic curve; rPP, SAP minus DAP; FC, fluid challenge; PLR, passive leg raising; ΔrPP-PLR, ΔrPP-FC, (rPP after PLR or FC minus rPP at baseline)/rPP at baseline.

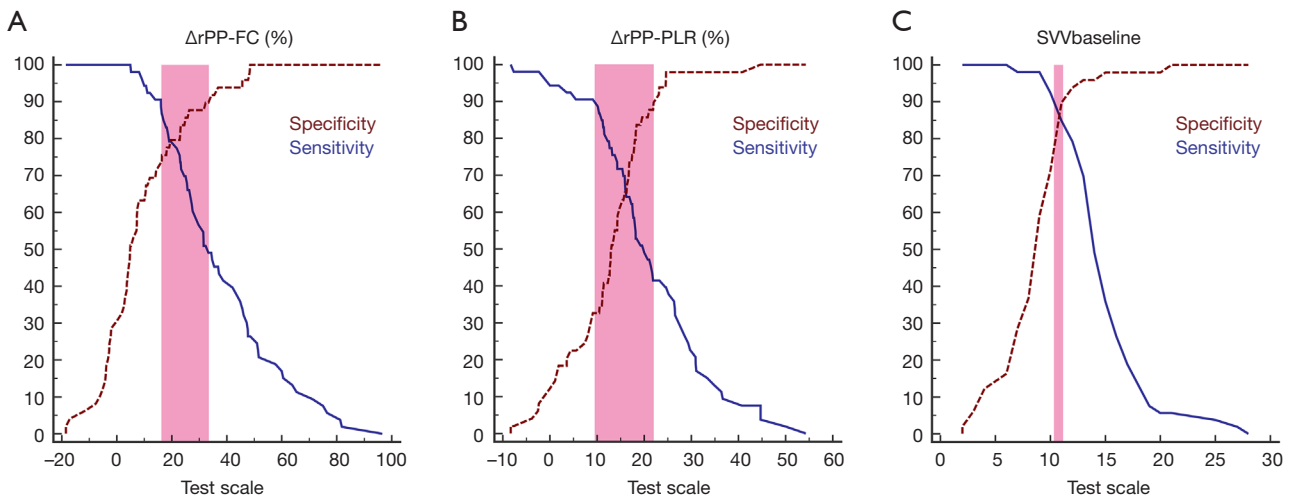

Figure 3 Two-graph ROC curves: sensitivity and specificity of ΔrPP-FC, ΔrPP-PLR, and SVV at baseline according to cut-off value for detection of >15% increase in stroke volume after fluid challenge. Inconclusive zone (>10% of diagnosis tolerance) is represented as a shaded rectangle. ROC, receiver operating characteristics; SVV, stroke volume variation; PLR, passive leg raising; FC, fluid challenge; SVVbaseline, stroke volume variation at baseline; ΔrPP-PLR (%), changes in radial artery pulse pressure induced by PLR; ΔrPP-FC (%), changes in radial artery pulse pressure induced by FC; ΔSV-FC (%), changes in stroke volume induced by FC.

induced by a FC could be used to detect the changes in SV with an acceptable grey zone. In contrast, the changes in rPP induced by PLR were unreliable in predicting fluid responsiveness.

Hemodynamic lability commonly occurs in the early period post cardiac surgery (23). Evaluation of volume status is one of the most difficult issues in hemodynamically unstable patients and it is crucial to detect whether the patient is responsive to fluid. Various indicators and tests have been introduced in patients under mechanical ventilation to predict fluid responsiveness (5-7,24,25). However, the majority of these methods requires direct measurement of SV by invasive or mini-invasive monitors (11). This raises an important issue since not all patients have continuous SV monitoring in the clinical scenarios (12).

PP is an indicator that is often ignored, despite its ability to provide important information. It is well-known that the SV-to-aortic PP ratio (SV/PP) has been proposed as an

Table 4 Validation studies concerning the changes of pulse pressure to detect fluid responsiveness

Study	Year	Monitoring Tool	Patients	Site	Sample Size	Intervention	AUC	r
Xavier Monnet (15)	2011	PiCCO	Septic shock	Femoral artery	228	Fluid challenge	0.78	0.56
Nicolas Dufour (14)	2011	PiCCO	Septic shock (44%)/ Cardiogenic shock (10%)	Femoral artery	39	Fluid challenge	0.89	0.60
Charalampos Pierrakos (17)	2012	PAC	Septic shock	Radial artery	51	Fluid challenge	0.62	0.28
Karim Lakhal (16)	2013	PiCCO	Septic shock (45%)/ Cardiogenic shock (15 %)	Femoral (75%)/ Radial artery (25%)	130	Fluid challenge	0.82	0.56
Victor De la Puente-Diaz de Leon (12)	2017	PAC	Septic shock	Radial artery	35	Fluid challenge	0.52	0.21
Zakaria Ait-Hamou (31)	2019	PiCCO	Septic shock (71%)/ Cardiogenic shock (5%)	Femoral artery	491	Fluid challenge	0.72	0.38

PAC, pulmonary artery catheter; PiCCO, pulse indicator continuous cardiac output; AUC, area under the receiver operating characteristic curve; r, Pearson correlation coefficient.

estimate of total arterial compliance at rest. In theory, if the arterial compliance remains stable, changes in PP should be parallel to the changes in SV. Although PP can be affected by vascular tone, this rarely has an impact over a short period of time. PP might thus be a potential candidate for bedside monitoring of the SV changes (26).

Changes in PP in the present study are different from the respiratory pulse pressure variation (PPV) previously described in mechanically ventilated patients (27). PPV can be calculated as the difference between the maximal value of pulse pressure (PPmax) and the minimal value of pulse pressure (PPmin) over a single respiratory cycle divided by their averaged value and expressed as a percentage: PPV (%) =100 × (PPmax – PPmin)/[(PPmax + PPmin)/2]. Studies have demonstrated that PPV can reliably predict fluid responsiveness in patients under mechanical ventilation (28-30). However, this method has several limitations and can only be used in strict conditions.

At present, it is still controversial whether the changes in PP can assess fluid responsiveness in patients. Several studies have investigated the ability of PP changes to evaluate CO changes after a FC in critically ill patients (*Table 4*) (12,14-17,31). Garcia *et al.* found that overall systemic vascular resistance did not change after a FC. Therefore, there was a strong correlation between changes in PP and changes in SV after a fluid challenge (r^2=0.79; P<0.0001) (32). Similar to the present findings, Monnet *et al.* demonstrated that the changes in PP acquired from a femoral artery and in CO after a FC were significantly correlated (r=0.56). A fluid-induced increase in PP of >17% allowed to detect a fluid-induced increase in CO of >15%, with a sensitivity of 65% and a specificity of 85%. Changes in PP did not reflect the changes in CO in patients treated with norepinephrine (r=0.21) (15). Furthermore, Dufour *et al.* found that there was a positive relationship between volume expansion-induced changes in SV and in PP at the femoral site (r=0.60). Increases in femoral PP of >9% indicated SV increases of >15%, with a sensitivity of 82% and a specificity of 95% (14).

In contrast to the above findings, De la Puente-Diaz de Leon *et al.* reported that rPP changes cannot serve as a surrogate to assess relative CO changes after a FC in mechanically ventilated septic patients (r=0.21). The AUROC curve for the relative changes in rPP to predict fluid responsiveness was 0.52 (95% CI: 0.31–0.72, P=0.8) (12). Pierrakos *et al.* also showed the lack of correlation between changes in rPP and SV after a fluid challenge in patients with septic shock (r^2=0.08, P=0.04). Similarly, rPP changes cannot differentiate the cardiac index in responders and non-responders (AUROC =0.618, 95% CI: 0.474–0.761, P=0.113) (17). Moreover, Ait-Hamou *et al.* found that fluid-induced changes in PP only roughly detected the fluid-induced changes in CO (r=0.38). The AUROC for changes in PP to detect a positive fluid response was 0.72 with a best diagnostic threshold of 10% (31).

Results of the present study are different with those

reported by Pierrakos *et al.* and De la Puente-Diaz de Leon *et al.* (12,17). In these two studies, all subjects in the group were septic shock patients, and all of them were monitored by radial artery pressure. However, patients were monitored by femoral artery pressure in other studies(14-16,31,32). Patients after cardiac surgery present with a different cardiovascular physiology compared to septic patients. Their cardiac function is often impaired in different degree after surgery, while the main causes of hypotension in septic shock are diffuse vasodilation, redistribution of intravascular fluid due to increased endothelial permeability and reduced arterial tension. Recent studies revealed that vascular function in patients with septic shock may present with some abnormalities, such as peripheral vascular decoupling and decreased vascular tone (33). Vasoactive drug (norepinephrine) dosage was significantly higher in the latter study compared to the present study (0.43 *vs.* 0.04 μg/kg/min) (12). It may cause a dissociation between the changes in radial and femoral arteries due to the large dose of vasoactive drugs. Therefore, rPP may not track SV in septic shock patients in these studies. This can partially explain why the results of the present study do not agree with studies conducted in septic patients.

The present study data showed that a significant increase in rPP correlated with an increase in SV (responders) only after a FC in patients after cardiac surgery. It was also found that changes in ΔrPP-PLR could not predict fluid responsiveness. PLR might induce sympathetic or cardiac reflex stimulation. In addition, it might be due to the change in arterial compliance caused by mechanical stretch during PLR, which affected the relationship between SV and rPP (34). Therefore, ΔrPP-PLR may not track SV changes.

Some limitations were present in the study. First, all patients were undergoing mechanical ventilation without spontaneous respiration. It is important to note that both arrhythmias and spontaneous breathing activity will lead to misreading of the pulse pressure. Second, although the FloTrac/Vigileo system can be directly connected to the radial artery catheter, the reliability of tracking SV changes is still under debate (35). Third, only the radial artery was used to measure arterial pressure in the present study. Whether study results can be extrapolated to other monitoring sites needs to be studied further.

Conclusions

In summary, the present study demonstrated that changes in rPP can help to detect the changes in SV after a fluid challenge with a smaller grey zone in mechanically ventilated patients after cardiac surgery. If rPP increase is >16% after the fluid challenge, an SV increase of ≥15% can be expected. By contrast, the changes in rPP should not be used for monitoring the effects of PLR on SV.

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Footnote

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