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Identification of volume parameters monitored with a noninvasive ultrasonic cardiac output monitor for predicting fluid responsiveness in children after congenital heart disease surgery

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Abstract

No previous study has used an ultrasonic cardiac output monitor (USCOM) to assess volume parameters, such as stroke volume variation (SVV), in order to predict the volume status and fluid responsivenes in children after congenital heart disease (CHD) surgery. The present prospective trial aimed to investigate the ability of SVV and corrected flow time (FTc), which were assessed with a USCOM, for predicting fluid responsiveness in children after CHD surgery.

The study included 60 children who underwent elective CHD surgery. Data were collected after elective CHD surgery. After arrival at PICU, the continuous invasive blood pressure was monitored. Once the blood pressure (BP) decreased to the minimum value, 6% hydroxyethyl starch (130/0.4) was administered (10 mL/kg) over 30 minutes for volume expansion (VE). The USCOM was used to monitor the heart rate, central venous pressure, stroke volume index (SVI), cardiac index, SVV, FTc of the children before and after VE. Additionally, the SVI change (ΔSVI) was calculated, and the inotropic score (IS) was determined. Children with a ΔSVI ≥15% were considered responders, while the others were considered nonresponders. The children were also divided into IS ≤10 and IS >10 groups.

Of the 60 children, 32 were responders and 28 were nonresponders. We found that only SVV was significantly correlated with ΔSVI ($r = 0.42$, $P < .01$). SVV could predict fluid responsiveness after surgery (area under the curve [AUC]: 0.776, $P < .01$), and the optimal threshold was 17.04% (sensitivity, 84.4%; specificity, 60.7%). Additionally, the SVV AUC was higher in the IS >10 group than in the IS ≤10 group (0.81 vs 0.73).

SVV measured with a USCOM can be used to predict fluid responsiveness after CHD surgery in children. Additionally, the accuracy of SVV for predicting fluid responsiveness might be higher among patients with an IS >10 than among those with an IS ≤10.

Abbreviations: ACCT = aortic cross-clamp time, ASD = combined with atrial septal defect, BP = blood pressure, CHD = congenital heart disease, CI = cardiac index, CPBT = cardiopulmonary bypass time, CVP = central venous pressure, EF = ejection fraction, FTc = corrected flow time, HR = heart rate, IS = inotropic score, PDA = patent ductus arteriosus, PiCCO = pulse indicator continuous cardiac output, SVI = stroke volume index, SVV = stroke volume variation, TOE = transoesophageal echocardiography, USCOM = ultrasonic cardiac output monitor, VE = volume expansion, VSD = ventricular septal defect.

Keywords: central venous pressure, congenital heart disease, corrected flow time, stroke volume variation, ultrasonic cardiac output monitor

1. Introduction

For an unstable hemodynamic state after congenital heart disease (CHD) surgery, volume expansion (VE) is preferred. However, because of limited cardiac function, uncorrected VE after cardiac surgery might cause many complications, such as tissue hypoperfusion, organ dysfunction, and pulmonary oedema.[1] A previous study indicated that only approximately 50% of patients in the intensive care unit (ICU) could benefit from VE.[1] Therefore, postoperative fluid management after CHD surgery might be challenging, and it is important to assess and monitor the pre-load state.

Traditional hemodynamic parameters, such as central venous pressure (CVP), have been shown to be unreliable for predicting fluid responsiveness;[2] however, dynamic parameters, such as stroke volume variation (SVV), which are based on the heart–lung interaction and reflect cyclic changes in stroke volume induced by mechanical ventilation in a closed-chest condition, have been shown to be reliable for predicting fluid responsiveness in many adult diseases.[3–5] However, because of differences in physiological factors, such as heart rate (HR), vascular elasticity, and chest wall compliance, between adults and children, it is not

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clear whether SVV can be used to accurately predict fluid responsiveness in children.

Flow time (FT) is the time required by the heart to generate a stroke volume, and it reflects the actual time of a systole. FT is generally adjusted to corrected flow time (FTc) based on a HR of 60 beats/min in order to facilitate comparison of different patients. The usefulness of FTc for predicting fluid responsiveness in children is controversial.[6–9]

Monitoring measures, such as pulse indicator continuous cardiac output (PiCCO) assessment, and transoesophageal echocardiography (TOE), have been shown to be appropriate for monitoring cardiac preload parameters.[10] Renner et al[2] showed the predictive accuracy of SVV for fluid responsiveness in a study on CHD, using PiCCO assessment and TOE. The authors stated that without a shunt, SVV could predict fluid responsiveness accurately. PiCCO assessment is invasive and has risks, such as infection, hemorrhage, and thrombosis. TOE requires professional personnel, and the collection of data is susceptible to interference, especially in patients under mechanical ventilation.[11] Therefore, PiCCO assessment and TOE are not widely performed in paediatric patients.

The ultrasonic cardiac output monitor (USCOM, Sydney, Australia) is a noninvasive hemodynamic monitoring system, which uses continuous Doppler ultrasound for monitoring, and it has benefits, such as portability, safety, dynamic monitoring, and easy operation. Jain et al[12] found that noninvasive Doppler ultrasonography was an accurate and safe alternative to pulmonary artery catheter insertion. This noninvasive method can monitor not only cardiac output and stroke volume, but also volume parameters, such as SVV and FTc. No previous study has used the USCOM to assess volume parameters, such as SVV, in order to predict the volume status and fluid responsivenes in children after CHD surgery. The aim of the present prospective trial was to investigate the ability of SVV and FTc, which were assessed with the USCOM, for predicting fluid responsiveness in children after CHD surgery.

2. Material and methods

2.1. Patients

The ethics of our study was strictly based on "Ethical principles and standards for the conduct of biomedical research and publication."[13] All parents of the participation of their children were completely voluntary and provided informed consent in the study. The present study was approved by the ethics committee of Children's Hospital of Chongqing Medical University. And all the patients met our inclusion criteria and exclusion criteria.

Inclusion criteria: Children were under sedation and underwent mechanical ventilation after elective CHD surgery for a single ventricular septal defect (VSD), or VSD combined with atrial septal defect (ASD), or patent ductus arteriosus (PDA); *Ventilator setting*: in volume control mode, with a tidal volume of 10 mL/kg, positive end expiratory pressure of $\leq 5\,cmH_2O$, and respiratory rate of < 30 breaths/min; no adjust the inotropic drug doses before and after VE.

Exclusion criteria: Children combined with complex CHD; Postoperative children with decreasing blood pressure, heart rate and oxyhemoglobin saturation who needed to rescue with cardiopulmonary resuscitation and high doses of inotropic drug; Children with postoperative arrhythmia or temporary pacemaker or intra-abdominal hypertension or subcutaneous emphysema; Ventilator set as pressure controlled or children out of a ventilator.

2.2. Hemodynamic monitoring and data collection

The USCOM was developed as a stand-alone device to measure and monitor cardiac output, using continuous-wave Doppler technology. The USCOM is approximately the size of common cardiac monitors. It has a touch screen, menu system interface, and small hand-held piezoelectric (2.2 MHz) Doppler ultrasound transducer. The transducer uses a wide acoustic beam to allow for easy detection of blood flow. The device monitored hemodynamic variables, such as the cardiac index (CI), stroke volume index (SVI), and SVV, using an ultrasonic probe. During monitoring, the patients were under sedation. The ultrasonic probe was placed on the sternum towards the aortic valve in order to determine the aorta flow pattern. The probe location was adjusted, and the most accurate Doppler blood flow spectrum was selected (Fig. 1). In all children, a central venous catheter was placed via the subclavian vein to measure CVP and a radial artery catheter was placed to continuously monitor the invasive arterial blood pressure.

Data were collected after elective CHD surgery. After arrival at PICU, the continuous invasive blood pressure was monitored. Once the blood pressure (BP) decreased to the minimum value (Table 1), 6% hydroxyethyl starch (130/0.4) was administered (10 mL/kg) over 30 minutes for VE, in order to achieve a stable hemodynamics.

Hemodynamic variables, including the HR, CVP, SVI, CI, SVV, and FTc were measured and recorded before VE and then 5 minutes after VE. In all patients administered inotropic drugs, such as dopamine, milrinone, and adrenaline (Adr), the dose was recorded and the inotropic score (IS) was calculated.

The IS was calculated as follow: IS = dopamine dose $\times$ 1 + dobutamine dose $\times$ 1 + amrinone dose $\times$ 1 + milrinone dose $\times$ 10 + Adr dose $\times$ 100 + isoprenaline dose $\times$ 100

2.3. Definition of fluid responsivenes

After surgery, all the children were classified according to the hemodynamic response to VE. Children with a change in the SVI (ΔSVI) of $\geq$15% in response to VE were considered to be responders, while the remaining children were considered nonresponders.[2]

2.4. IS groups

Inotropic drugs were used to maintain hemodynamic balance. In order to evaluate the effect of the inotropic drugs on hemodynamic parameters, such as SVV, we divided the patients into the following groups according to the IS value: IS $\leq$10 group and IS $>$10 group.

2.5. Statistical analysis

Data are expressed as means $\pm$ standard deviations. The data obtained before and after volume expansion in the responders/nonresponders were compared using the paired *t*-test. The data of the responders and nonresponders at each time point were compared using the independent sample *t*-test. Pearson correlation analysis was performed for data that were normally distributed, while Spearman's correlation analysis was performed for data that were not normally distributed. The abilities of the CVP, SVV, and FTc to predict fluid responsiveness were assessed using receiver operating characteristic (ROC) curve analysis. All statistical analysis was performed using SPSS 17.0 (IBM Corp., Armonk, NY). A *P*-value $<.05$ was considered statistically significant.

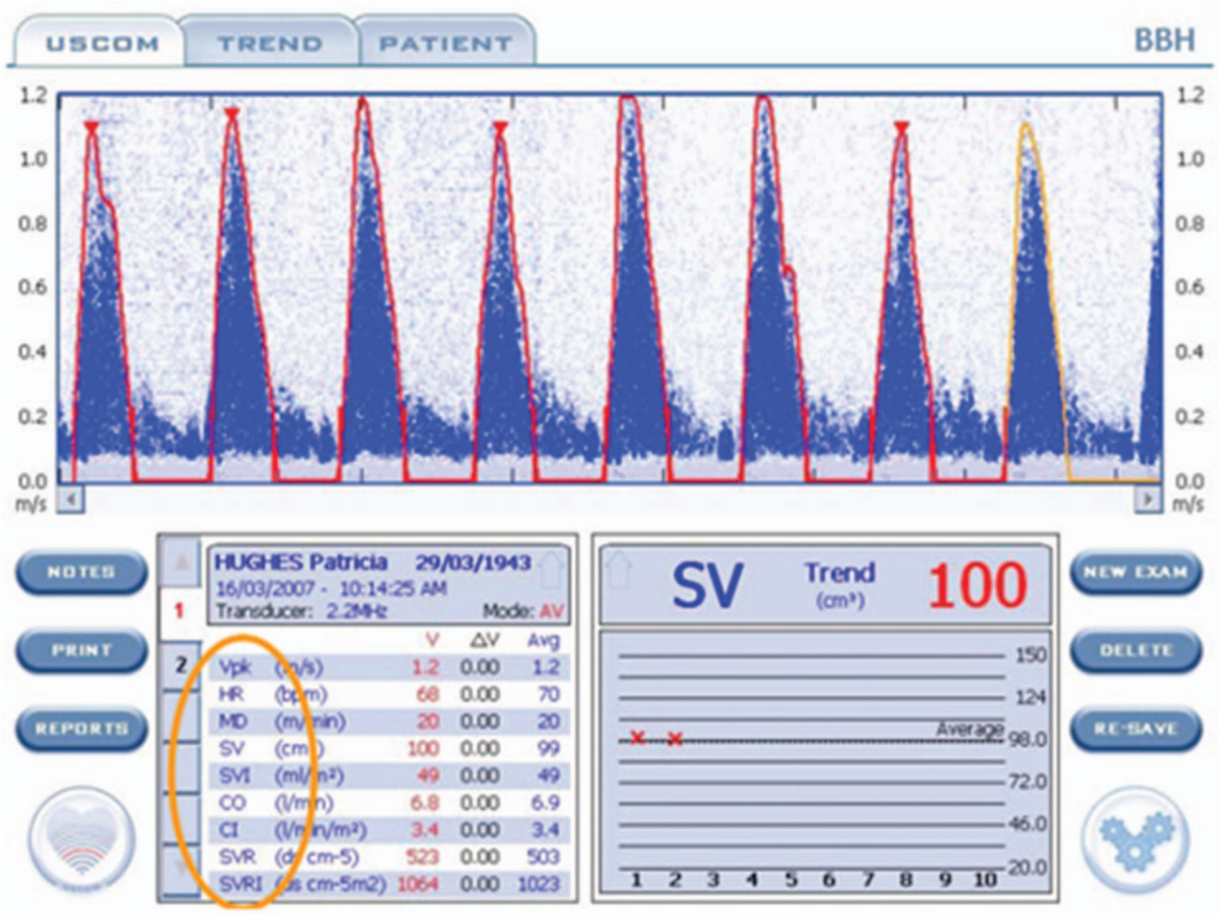

Figure 1. Standard blood flow spectrum.

3. Results

3.1. Patient characteristics

The present study enrolled 60 patients (31 males and 29 female patients) who underwent surgical correction for a VSD, an ASD, or a concomitant PDA. The mean (SD) age, weight, cardiopulmonary bypass time (CPBT), and aortic cross-clamp time (ACCT) were 10.90 (14.63) months, 6.68 (2.68) kg, 79.58 (21.07) minutes, and 36.95 (14.60) minutes, respectively. After surgery, all patients received dopamine (5–10 μg/kg/min), milrinone (0.5–0.75 μg/kg/min), or adrenaline (0.01–0.1 μg/kg/min) to maintain hemodynamic balance. Additionally, midazolam was used for sedation and sufentanil was used for analgesia. No complications associated with VE were noted, and no deaths occurred. All patients were discharged without any issues.

3.2. General clinical data of the responders and nonresponders

The general clinical data of the responders and nonresponders are presented in Table 2. Of the 60 patients, 32 were responders and 28 were nonresponders. We found that sex, age, weight, CPBT, and ACCT were similar between the responders and nonresponders.

3.3. Hemodynamic variables before and after VE among the responders and nonresponders

The hemodynamic variables before and after VE are presented in Table 3. Before VE, only SVV was significantly larger among the responders than among the nonresponders ($P < .01$). Among the responders, the SVI, CI, CVP and FTc were higher, and SVV was

Table 1

The normal range of blood pressure of children.

	Systolic blood pressure, mm Hg		Diastolic blood pressure, mm Hg	
Age, months	Minimum value	Maximum value	Minimum value	Maximum value
Neonate	65	90	45	60
1–12	75	100	50	70
12–36	80	110	50	78
36–50	82	112	50	80

Table 2

General clinical data of the responders and nonresponders after VE.

	Age, months	Weight, kg	IS	CPBT, minutes	ACCT, minutes
Responders (n = 32)	13.0 ± 17.7	7.1 ± 3.1	11.7 ± 1.8	81.5 ± 21.9	37.5 ± 12.9
Nonresponders (n = 28)	8.5 ± 9.9	6.2 ± 2.1	12.3 ± 2.6	77.8 ± 20.4	36.39 ± 16.6
P-value	.23	.20	.27	.55	.75

Data are presented as means ± standard deviations or number of patients.

ACCT = aortic cross clamp time, CPBT = cardiopulmonary bypass time, IS = inotropic score, VE = volume expansion.

No significant difference was observed between the responders and nonresponders.

A *P*-value <.05 was considered statistically significant.

Table 3

Hemodynamic variables of responders and nonresponders after VE.

	Responders (n = 32)		Nonresponders (n = 28)	
	Before VE	After VE	Before VE	After VE
HR, bpm	149.3 ± 19.1	147.8 ± 17.4	151.9 ± 21.5	151.6 ± 19.8
SVI, mL/m^2	37.2 ± 10.0	45.6 ± 11.7†	43.4 ± 12.7	45.7 ± 13.7†
CI, L/min/m^2	5.4 ± 1.77	6.7 ± 2.0†	6.6 ± 2.1	6.9 ± 2.3†
CVP, mm Hg	7.8 ± 3.3	9.8 ± 3.4†	8.2 ± 2.7	9.1 ± 2.9
SVV (%)	19.40 ± 2.61*	13.63 ± 2.20†	16.12 ± 3.37	12.65 ± 2.31†
FTc, ms	323.79 ± 34.21	337.96 ± 30.88†	328.85 ± 26.70	328.93 ± 25.53

Data are presented as means ± standard deviations.

CI = cardiac index, CVP = central venous pressure, FTc = corrected flow time, HR = heart rate, SVI = stroke volume index, SVV = stroke volume variation, VE = volume expansion.

* *P* <.05 vs nonresponders at each time point.

† *P* <.05 vs before VE (baseline) within a group.

A *P*-value <.05 was considered statistically significant.

lower after VE than before VE ($P < .05$). Among the nonresponders, the SVI, CI were higher, and SVV was lower after VE than before VE ($P < .05$); however, the HR, CVP, and FTc did not significantly change ($P > .05$).

3.4. Correlation analysis of the CVP, SVV, and FTc with ΔSVI for all the patients

The results of correlation analysis of the CVP, SVV, and FTc with ΔSVI for all the patients are presented in Table 4. We found that only SVV was significantly correlated with ΔSVI ($r = 0.42$, $P < .01$)

3.5. ROC analysis for all the patients

Among all the patients, the AUC of SVV (AUC = 0.776) was found to be the most appropriate for identifying a ΔSVI of ≥15%. In ROC analysis, the optimal threshold was 17.04%, with a sensitivity of 84.4% and a specificity of 60.7% (Table 5).

3.6. Comparison of the IS groups before and after fluid therapy

Comparison of the IS groups before and after fluid therapy is presented in Table 6. Before VE, in the IS ≤10 group, only SVV was significantly different between responders and nonresponders, while in the IS >10 group, only the SVV and SVI were significantly different between responders and nonresponders. In the IS ≤10 group, only the HR and FTc were significantly different before and after VE among responders, while the HR, SVI, CI, and FTc were significantly different before and after VE among nonresponders. In the IS >10 group, all parameters were significantly different before and after VE among responders, while all parameters, except the HR, CVP, and FTc, were different before and after VE among nonresponders.

3.7. Correlation analysis of the CVP, SVV and FTc with ΔSVI for the IS groups

The results of correlation analysis of the CVP, SVV, and FTc with ΔSVI for the IS groups are presented in Table 4. We found that

Table 4

Correlation of the hemodynamic data before VE with ΔSVI among all the patients and the IS groups.

	Total		IS ≤10 group		IS >10 group	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value
CVP	−0.09	.52	−0.3	.13	0.09	.62
SVV	0.42	<.01	0.35	.08	0.52	<.01
FTc	−0.13	.32	−0.19	.35	−0.09	.62

CVP = central venous pressure, FTc = corrected flow time, SVV = stroke volume variation

A *P*-value <.05 was considered statistically significant.

Table 5

Results of receiver operating characteristics curve analysis.

	AUC	Optimal threshold value (sensitivity/specificity, %)	*P*-value
CVP	0.508	9.5 (37.5/78.6)	.92
SVV	0.776	17.04 (84.4/60.7)	<.01
FTc	0.446	343.17 (34.3/75)	.48

AUC = area under the curve, CVP = central venous pressure, FTc = corrected flow time, SVV = stroke volume variation.
A *P*-value <.05 was considered statistically significant.

Table 6

Comparison of hemodynamic data before and after VE in the IS groups.

	IS ≤10 group (n = 26)				IS >10 group (n = 34)			
	Responders (n = 14)		Nonresponders (n = 12)		Responders (n = 18)		Nonresponders (n = 16)	
	Before VE	After VE	Before VE	After VE	Before VE	After VE	Before VE	After VE
HR, bpm	143.62 ± 19.06	144.12 ± 17.46	149.49 ± 17.2	147.71 ± 15.07	153.66 ± 18.44	150.64 ± 17.26[b]	153.68 ± 24.63	154.57 ± 22.71
SVI, mL/m^2	37.46 ± 11.30	45.74 ± 13.24[b]	39.63 ± 6.10	41.45 ± 9.78	36.90 ± 2.16[a]	45.52 ± 10.79[b]	46.28 ± 13.99	48.87 ± 15.52[b]
CI, L/min/m^2	5.2 ± 1.77	6.5 ± 1.96[b]	5.87 ± 1.43	6.10 ± 1.48	5.60 ± 1.80[a]	6.89 ± 2.05[b]	7.10 ± 2.35	7.50 ± 2.61[b]
CVP, mm Hg	7.14 ± 3.92	8.79 ± 3.68[b]	7.42 ± 1.56	8.25 ± 1.91[b]	8.33 ± 2.74	10.56 ± 2.30[b]	8.81 ± 3.21	9.81 ± 3.29
SVV (%)	19.42 ± 3.08[a]	13.03 ± 2.19[b]	15.95 ± 4.4	13.47 ± 2.48[b]	19.37 ± 2.28[a]	13.87 ± 2.05[b]	16.25 ± 2.57	12.03 ± 2.05[b]
FTc, ms	336.08 ± 34.40	348.21 ± 33.40	331.19 ± 18.34	334.86 ± 23.21	314.23 ± 31.75	329.99 ± 27.06[b]	327.09 ± 32.08	324.48 ± 26.99

Data are presented as means ± standard deviations.
CI = cardiac index, CVP = central venous pressure, FTc = corrected flow time, HR = heart rate, SVI = stroke volume index, SVV = stroke volume variation, VE = volume expansion.
[a] *P* < .05 vs nonresponders at each time point.
[b] *P* < .05 vs before VE (baseline) within a group.
A *P*-value <0.05 was considered statistically significant.

only in the IS >10 group, SVV was significantly correlated with ΔSVI ($r = 0.52$, $P < .01$).

3.8. ROC analysis for the IS groups

In the IS ≤10 group, the AUC of SVV (AUC = 0.732) was found to be the most appropriate for identifying a ΔSVI of ≥15% after VE. In ROC analysis, the optimal threshold was 15.62%, with a sensitivity of 92.9% and a specificity of 50% (Table 7). Additionally, in the IS >10 group, the AUC of SVV (AUC = 0.813) was found to be the most appropriate for identifying a ΔSVI of ≥15% after VE. In ROC analysis, the optimal threshold was 17.04%, with a sensitivity of 88.9% and a specificity of 62.5% (Table 7).

4. Discussion

The present study found that SVV monitored with a noninvasive USCOM could predict fluid responsiveness after CHD surgery in children and that the CVP and FTc could not predict fluid responsiveness after the surgery. Additionally, the accuracy of SVV for predicting fluid responsiveness was higher among patients with an IS >10 than among those with an IS ≤10.

CVP is currently the most common clinical preload monitoring indicator. We found that CVP had no correlation with ΔSVI ($P > 0.05$), and ROC analysis showed that CVP could not predict fluid responsiveness accurately, which is consistent with the finding of Renner et al.[2]

FTc might be useful for predicting fluid responsiveness in children. Previous studies showed that FTc might be a better preload parameter than CVP or PAWP for predicting fluid responsiveness accurately.[6,7] Additionally, an animal study indicated that fluid responsiveness might be better reflected by FTc than by SVV in cases of hypovolemia and hypervolemia.[8] However, in the present study, FTc was not correlated with ΔSVI, and ROC analysis showed that FTc could not predict fluid responsiveness after CHD surgery in children. These different findings might have been obtained because FTc reflects the actual time of a systole, it can be influenced by cardiac preload and afterload, or it is closely related to myocardial contractility. In the present study, the study patients were children who underwent CHD surgery. Myocardial contractile dysfunction caused by

Table 7

Results of receiver operating characteristics analysis for IS groups.

	Group ≤10			Group IS>10		
	AUC	Optimal threshold value (sensitivity/specificity, %)	*P*-value	AUC	Optimal threshold value (sensitivity/specificity, %)	*P*-value
CVP	0.524	9.5 (42.9/91.7)	.84	0.488	8.5 (50/56.2)	.9
SVV	0.732	15.62 (92.9/50)	.045	0.813	17.04 (88.9/62.5)	.002
FTc	0.554	357.13 (21.4/100)	.64	0.375	340.41 (22.2/75)	.21

AUC = area under the curve, CVP = central venous pressure, FTc = corrected flow time, SVV = stroke volume variation.
A *P*-value <.05 was considered statistically significant.

cardiac ischemia, hypoxia, reperfusion injury due to cardiopulmonary bypass, or direct damage to the myocardium during surgery might prevent FTc from predicting fluid responsiveness after CHD surgery in children. A previous study also showed that FTc could not predict fluid responsiveness in patients with circulatory failure.[9]

SVV is a functional indicator for the cardiopulmonary interaction mechanism to evaluate the volume state and predict fluid responsiveness. In adults, the predictive accuracy for fluid responsiveness after fluid therapy has been shown to be higher with SVV than with static preload parameters, such as CVP and PAWP.[3,4] Goal-directed fluid therapy has been advocated strongly, and it has been shown that the incidence of complications, such as pulmonary oedema, would reduce if the goal of fluid therapy is set at an SVV of $<10\%$.[5] The HR is higher, blood vessel elasticity is better, and thoracic compliance is better in children than in adults. Therefore, the ability of SVV to accurately predict fluid responsiveness in children should be investigated further. A previous animal study[14] and 3 clinical studies[2,15,16] explored the application of SVV for monitoring fluid responsiveness and guiding fluid therapy in children. Renner et al[2] used PiCCO assessment and transoesophageal echocardiography to investigate the fluid responsiveness of children both before and after CHD surgery. The authors found that SVV could not predict fluid responsiveness when a left-to-right shunt was present but could accurately predict fluid responsiveness after the shunt was repaired. In their study, the AUC was 0.78 and the diagnostic threshold was 15%.

Invasive procedures are associated with complications, such as infection, trauma, and bleeding. Therefore, with advances in the medical field, noninvasive and continuous monitoring will replace invasive monitoring in children in the future. In the present study, we used a noninvasive USCOM to measure parameters for assessing fluid responsiveness. We found that SVV was higher among responders than among nonresponders before fluid therapy and that SVV was significantly correlation with ΔSVI. The AUC was 0.776, and the threshold value was 17.04%, with a sensitivity of 84.4% and a specificity of 60.7%, indicating that SVV assessed with the noninvasive USCOM could predict fluid responsiveness after CHD surgery in children. Lee et al[15] used a noninvasive cardiac output monitor to measure SVV in order to investigate the responsiveness of children under mechanical ventilation after ventricular septal defect repair. The authors found that SVV reliably predicted fluid responsiveness, with a diagnostic threshold value of 10%, which is lower than the threshold value in our study. The difference might have been caused by differences in monitoring equipment and measurements. Lee et al[15] found that the CI was lower by approximately 25% when measured with a noninvasive cardiac output monitor than with an echocardiography system, and this might explain the difference noted. Additionally, continuous infusion of inotropic drugs, such as dopamine, milrinone, and adrenaline, might have increased the diagnostic threshold value of SVV in the present study.

SVV is a cardiopulmonary correlation dynamic parameter, and the predictive value of SVV can be affected by factors, such as breathing patterns, tidal volume (Ti), respiratory rate, spontaneous breathing, cardiac arrhythmia, vascular compliance, and abdominal pressure.[14,17–19] Therefore, in order to reduce the influence of such factors on the results, the study selected children based on strict inclusion and exclusion criteria. However, the use of inotropic drugs could not be avoided after surgery. Therefore, according the use of inotropic drugs, we calculated the IS and divided the children into IS ≤ 10 and IS >10 groups. The study found that in both the groups, the AUCs of SVV were more than 0.7, indicating that SVV could predict fluid responsiveness in the groups. Additionally, the AUC of SVV was higher in the IS >10 group than in the IS ≤ 10 group (0.81 vs 0.73), indicating that SVV could better predict fluid responsiveness in patients with an IS of >10. This finding might have been obtained because large doses of inotropic drugs can shift the Frank–Starling curve to the upper left, resulting in a situation where in the SVV appears to accurately predict fluid responsiveness. Monnet et al[19] showed that in fluid therapy for patients grouped according to cardiac ejection fraction (EF) measured with echocardiography, the AUC of SVV was significantly higher in patients with a high EF than in those with a low EF. Therefore, SVV might show better accuracy in patients with good cardiac function than in patients with poor cardiac function.

In the present study, the diagnostic thresholds of SVV were 17.04% for the IS >10 group and 15.62% for the IS ≤ 10 group. This difference might be associated with the use of inotropic drugs, including dopamine, milrinone, and adrenaline. A previous study investigated the influence of inotropic drugs on SVV.[20] The authors found that vasodilators increased SVV, while cardiotonic agents and vasoconstrictors did not change the SVV value. Therefore, inotropic drugs can affect the diagnostic threshold of SVV, and when using SVV to predict fluid responsiveness, the IS should be considered when determining the threshold.

In the present study, the use of the noninvasive USCOM helped avoid complications, such as infection, vasculitis, thrombosis, hematoma, and bleeding, which are associated with invasive procedures, and no complications were found to be caused by the use of the monitor. Previous studies indicated that cardiac output monitored with a USCOM is correlated with cardiac output monitored with invasive methods.[12,21] The USCOM is easy to operate and grasp, and it can be easily used by general medical staff after only 20 to 30 training sessions. Therefore, it is suitable for clinical application.

The USCOM uses continuous wave Doppler to monitor the cross-sectional area percutaneously; therefore, it might not be suitable for monitoring the hemodynamics of the tetralogy of Fallot and other CHDs combined with outflow tract malformations. Further studies are needed to investigate the monitoring of hemodynamics after surgery in children with all types of CHDs in order to ensure the health of these children.

In conclusion, SVV measured with a USCOM can be used to predict fluid responsiveness after CHD surgery in children. The present study found that the diagnostic threshold of SVV was 17.04%, with a sensitivity and specificity of 84.4% and 60.7%, respectively. Additionally, the accuracy of SVV for predicting fluid responsiveness might be higher among patients with an IS >10 than among those with an IS ≤ 10.

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Author contribution

Yu-wei Cheng, Feng Xu and Jing Li conceived and designed the experiments; Yu-wei Cheng performed the experiments; Yu-wei

Cheng and Jing Li analyzed the data; Yu-wei Cheng wrote the paper.

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Data curation: Yu-wei Cheng.
Formal analysis: Yu-wei Cheng, Jing Li.

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