Original Article

Respiratory variation in aortic flow peak velocity and inferior vena cava distensibility as indices of fluid responsiveness in anaesthetised and mechanically ventilated children

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ABSTRACT

Background and Aims: Dynamic parameters such as the respiratory variation in aortic flow peak velocity (ΔVpeak) and inferior vena cava distensibility index (dIVC) are accurate indices of fluid responsiveness in adults. Little is known about their utility in children. We studied the ability of these indices to predict fluid responsiveness in anaesthetised and mechanically ventilated children. **Methods:** This prospective study was conducted in 42 children aged between one to 14 years scheduled for elective surgery under general endotracheal anaesthesia. Mechanical ventilation was initiated with a tidal volume of 10 ml/kg. ΔVpeak, dIVC and stroke volume index (SVI) were measured before and after volume expansion (VE) with 10 ml/kg of crystalloid using transthoracic echocardiography. Patients were considered to be responders (R) and non-responders (NR) when SVI increased to either ≥15% or <15% after VE. ΔVpeak and dIVC were analysed between R and NR. **Results:** The best cut-off value for ΔVpeak as defined by the receiver operator characteristics (ROC) curve analysis was 12.2%, for which sensitivity, specificity, positive predictive value and negative predictive value were 100%, 94%, 96% and 100%, respectively, the area under the curve was 0.975. The best cut-off value for dIVC as defined by the ROC curve analysis was 23.5%, for which sensitivity, specificity, positive predictive value and negative predictive value were 91%, 89%, 91% and 89%, respectively, the area under the curve was 0.95. **Conclusion:** ΔVpeak and dIVC are reliable indices of fluid responsiveness in children.

Key words: Central venous pressure, echocardiography, paediatric anaesthesia, stroke volume, vena cava, volume expansion

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INTRODUCTION

The ideal index of fluid responsiveness for use in a critically care unit or for a patient undergoing major surgical procedure should be sensitive to changes in loading conditions, reproducible, simple to use and non-invasive. Widely available static parameters such as central venous pressure (CVP), pulmonary capillary wedge pressure or measurement of the left ventricular end diastolic area (LVEDA) or left ventricular end diastolic volume by echocardiography (ECHO) have been shown to be poor predictors of fluid responsiveness.[1,2] Hence, measuring dynamic parameters such as respiratory variation in arterial pulse pressure, systolic pressure, pulse oximetry plethysmographic waveform amplitude, aortic flow peak velocity (Vpeak) and inferior vena cava (IVC) diameter have been proposed as better indices of

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fluid responsiveness.[3-8] They reflect the dynamic changes in the circulation that occur due to cardio respiratory interaction. Positive pressure ventilation induces cyclical changes in right ventricular stroke volume (SV), in turn, left ventricular SV. This variation in SV is more pronounced in the hypovolemic state, which can be identified using dynamic parameters.

Above-mentioned parameters are said to indicate changes in left ventricular SV with respect to a change in intravascular volume status and have been validated as indices of fluid responsiveness in the adult population. However, little is known about the ability of these indices to predict fluid responsiveness in children. Studies have shown that arterial waveform derived parameters are of little value in children and is attributed to their higher vascular compliance.[8] Hence, we conducted our study to investigate the ability of Vpeak and IVC diameter measured by transthoracic ECHO as indices of fluid responsiveness in anaesthetised and ventilated paediatric patients.

The objective of the study was to evaluate the ability of respiratory variation in Vpeak (ΔVpeak) and IVC distensibility index (dIVC) to predict fluid responsiveness in anaesthetised and mechanically ventilated children.

METHODS

This prospective study was commenced after obtaining the approval of the Departmental Dissertation Committee and Institutional Ethics Committee. A detailed pre-operative evaluation of the patients was done, the day prior to the surgery and written informed consent was obtained from the parent or the guardian. Paediatric patients aged 1–14 years, belonging to American Society of Anesthesiologist's physical status Class I scheduled for elective surgery under general endotracheal anaesthesia, were included in the study. Surgeries performed were ENT, orthopaedics, abdominal wall and other general surgeries. Patients were excluded if they had congenital heart disease, arrhythmias, renal disorders or raised intra-abdominal pressure. Patients in whom there was difficulty in obtaining ECHO images or technical difficulty were excluded from the study.

There were four investigators in the study. Investigator 1 had done the pre-operative evaluation, ensured nil-per-oral status, obtained written informed consent and noted all study parameters, whereas Investigator 2 had administered premedication, performed induction/maintenance of anaesthesia, intubation of the trachea and established positive pressure ventilation. Investigator 3 was an experienced echocardiographer who performed the ECHO, measured and recorded study parameters. Investigator 4 was the cardiologist, who was blinded for the study had analysed the recorded and measured parameters obtained by the Investigator 3.

After establishing standard monitors (non-invasive blood pressure [NIBP], 3 electrode electrocardiogram and pulse oximetry), anaesthesia was induced with 6.0% sevoflurane in O_2 using circle absorber system and an appropriate gauge peripheral intravenous (IV) line was secured. Supplemental doses of IV propofol were administered as appropriate. Analgesia and muscle paralysis were obtained with 2 μg/kg of IV fentanyl and 0.1 mg/kg of IV vecuronium, respectively. Intubation of the trachea was done with an appropriate sized endotracheal tube as decided by the consultant anaesthesiologist in-charge of the patient. IV line was connected to 1% dextrose Ringer's lactate (DRL) through a burette system and set at a minimum flow.

Positive pressure ventilation was initiated using, anaesthesia workstation ventilator (Datex Ohmeda Aestiva/5™, GE Healthcare, Connecticut, USA), in volume control mode with a tidal volume of 10 ml/kg, respiratory rate adjusted to the age (refer appendix) and an I:E ratio of 1:2 without PEEP. Anaesthesia was maintained with isofluranae in O_2/N_2O (50%/50%) titrated to achieve a MAC of 1. Heart rate (HR), NIBP and SpO_2 values were noted at regular interval throughout the study period.

After achieving a steady state MAC value of 1.0, the Investigator 3 performed transthoracic ECHO using echocardiography (Vivid e™, GE Healthcare, Connecticut, USA). A linear paediatric probe with frequency adjusted between 3.5 and 6.0 MHz was used to perform ECHO as appropriate. After obtaining an apical five-chamber view, pulsed-wave Doppler was used to record aortic flow at the level of left ventricular outflow tract (LVOT). The ECHO probe was kept parallel to LVOT for recording. IVC was visualised in subcostal long axis view and M-mode was used to generate a time motion record of IVC diameter approximately at the level of hepatic vein junction. LVOT diameter was measured by the parasternal long axis view in all patients to calculate LVOT area and to derive SV.

Over a single respiratory cycle, several consecutive values of aortic velocity time integral (VTI*ao*) and corresponding Vpeak were recorded. Three such measurements were done and averages of mean VTI*ao* and ΔVpeak were taken for analysis [Figure 1]. The ECHO imaging was coordinated with respiratory cycle by visual monitoring of excursion of the ventilator bellow because an option for superimposition of the ventilatory cycle on ultrasound monitor was not available.

Similarly, over a single respiratory cycle maximum IVC diameter (D_{max}) and minimum IVC diameter (D_{min}) were measured. Three such measurements were done and mean values were taken for analysis [Figure 2].

A fluid challenge of 10 ml/kg of 1% DRL was administered by the Investigator 2 over a period of 5–10 min. Immediately, after fluid challenge, IVC diameter and Doppler aortic flow were recorded again in a similar manner. Further analysis of the Doppler parameters was done by Investigator 4.

Subsequent anaesthetic management was carried out as per the discretion of the consultant anaesthesiologist in-charge of the patient. Patients were monitored throughout the procedure and post-operatively, for desaturation or any untoward event till they were discharged to the ward.

The parameters derived were stroke volume index (SVI) respiratory variation in aortic flow peak velocity and IVC distensibility index (dIVC).

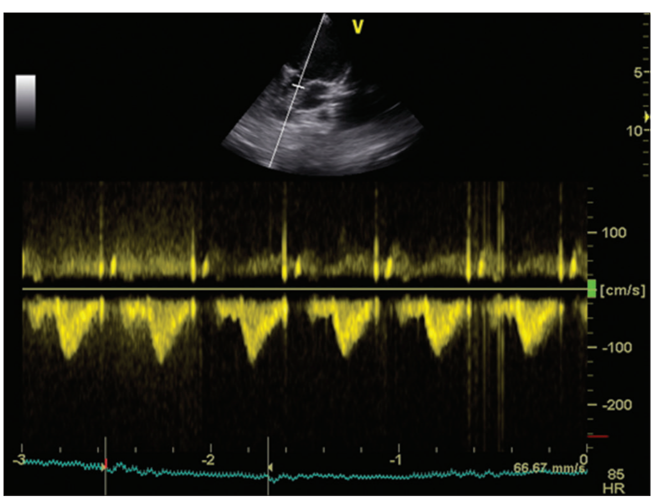

Figure 1: Transthoracic five chamber view and recording of aortic flow peak velocity and velocity time integral

Stroke volume index

VTI*ao* is the area under the velocity-time curve during systole. It represents the distance, the blood is ejected with each beat and when multiplied by LVOT area yields SV. (SV = VTI*ao* × LVOT area).

Stoke volume is indexed to body surface area (BSA): SVI = SV/BSA.

Volume expansion (VE) after the fluid challenge is seen as an increase in average VTI*ao*, in turn, SVI. Patients were respectively classified as responders (R) and non-responders (NR) based on a change in SVI >15% or ≤15% respectively after VE.

Respiratory variation in aortic flow peak velocity

Vpeak is the maximum velocity of the aortic blood flow recorded by pulsed-wave Doppler at the level of aortic annulus. ΔVpeak is calculated as the percentage change in Vpeak in one respiratory cycle. Three such ΔVpeak obtained in three different respiratory cycles were averaged for analysis.

$$\Delta Vpeak = Vpeak_{max} - Vpeak_{min}/(Vpeak_{max} + Vpeak_{min})/2 \times 100$$

Where, $Vpeak_{max}$ is the maximum aortic flow velocity and $Vpeak_{min}$ is the minimum aortic flow velocity recorded over a single respiratory cycle in m/s.

The change in ΔVpeak is compared in R and NR.

IVC distensibility index

The distensibility of IVC (dIVC) in percentage was calculated as follows:

$$dIVC = D_{max} - D_{min}/D_{min} \times 100$$

Change in dIVC was compared in R and NR.

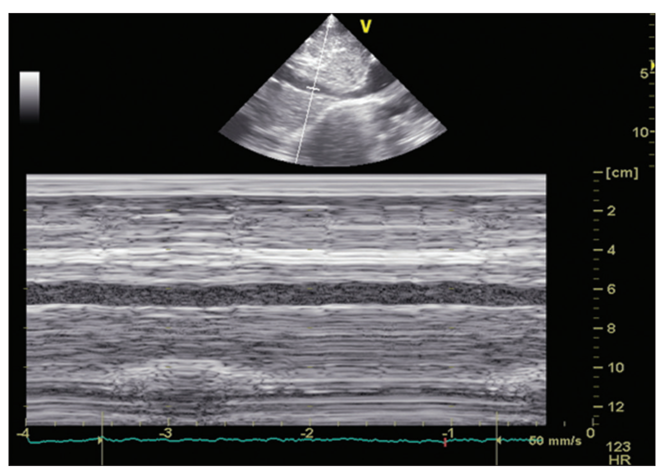

Figure 2: Recording of inferior vena cava diameter in M-mode

RESULTS

This prospective study was conducted between December 2012 and June 2014. Receiver operator characteristics (ROC) curve was applied for a pilot study data which included 10 cases. Taking a 95% confidence interval and 5% error, sample size calculated was 32. We could conduct the study in 42 patients in above specified time. Results were expressed as a mean ± standard deviation. Fisher's exact test, Student's *t*-test and ANOVA were used for statistical analysis along with ROC curve analysis. Patients showing an increase in SVI of >15% after fluid challenge were classified as R ($n = 24$), whereas those with ≤15% were classified as NR ($n = 18$).

Table 1 depicts the demographic characteristics of the study group, which shows no statistical difference between R and NR with respect to age, sex, height, weight and BSA. Table 2 shows the difference in study parameters, i.e. ΔVpeak (%) and dIVC (%) between R and NR.

Before VE, ΔVpeak was higher in R than in NR. All R had a ΔVpeak ≥12.2% while 17 of 18 NR had ΔVpeak <12.2%. The best cut-off value for ΔVpeak as defined by the ROC curve analysis was 12.2%, for which sensitivity, specificity, positive predictive value and negative predictive value were 100%, 94.4%, 96% and 100%, respectively, the area under the curve was 0.975 [Figure 3].

Similarly, before VE, dIVC was higher in R than in NR. 22 out of 24 R had dIVC of ≥23.5%, whereas 16 out of 18 NR had dIVC of <23.5%. The best cut-off value for dIVC as defined by the ROC curve analysis was 23.5%, for which sensitivity, specificity, positive predictive value and negative predictive value were 91%, 89%, 91.7% and 88.9% respectively, the area under the curve was 0.94 [Figure 4].

DISCUSSION

The outcome of our study was that in anaesthetised and mechanically ventilated children, ΔVpeak and dIVC measured by transthoracic and subcostal ECHO respectively are reliable indicators of fluid responsiveness.

Static parameters are widely used for assessing volume responsiveness in patients undergoing major

Table 1: Demographic characteristics

	Responder (R) *n*=24	Non-responder (NR) *n*=18	*P* value
Male	18	14	1.00*
Female	6	4	
Age (years)	6.5±3.9	6.2±4.1	0.80#
Weight (kg)	19±8.3	18.8±8.3	0.94#
Height (cm)	111.5±21.5	110±24	0.84#
BSA (m^2)	0.75±0.24	0.76±0.23	0.92#

*Fisher's exact test. #Independent student *t*-test. NR – Non-responders; R – Responders; BSA – Body surface area

Table 2: Study parameters compared between R and NR

	Group	Pre VE	Post VE	*P* value*
SVI	R	37±7	47±9	<0.001
	NR	45±7	48±7	
ΔVpeak (%)	R	18±5	4±2	<0.001
	NR	9±3	5±2	
dIVC (%)	R	47±16	17±6	<0.001
	NR	15±7	13±6	

*Repeated measures ANOVA for the pre volume expansion values. SVI – Stroke volume index; dIVC – Inferior vena cava distensibility index; ΔVpeak – Aortic flow peak velocity; VE – Volume expansion; NR – Non-responders; R – Responders

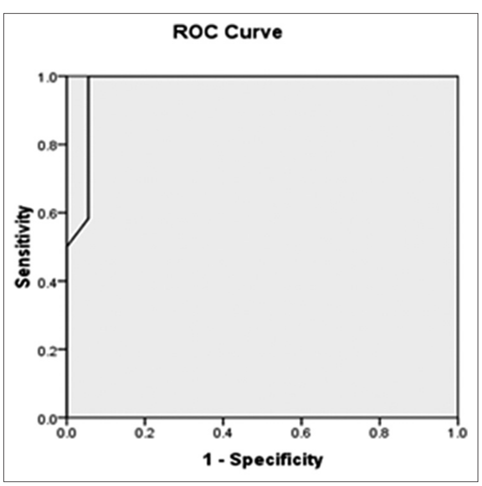

Figure 3: Area under receiver operator characteristics curve for respiratory variation in aortic flow peak velocity

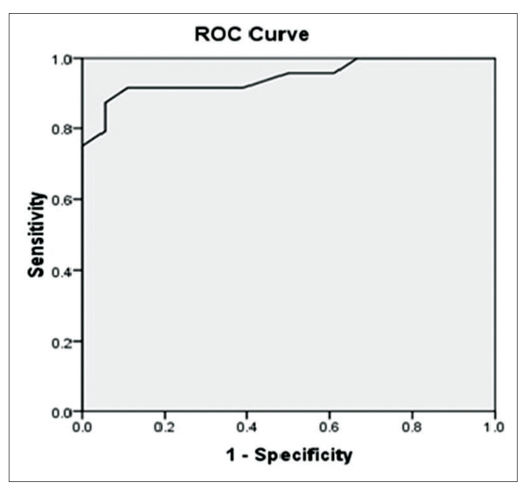

Figure 4: Area under receiver operator characteristics curve for inferior vena cava distensibility index

surgery and in critically ill patients. Commonly used parameters are CVP, pulmonary artery occlusion pressure and LVEDA, each of these has their limitation and is not a reliable indicator of fluid responsiveness. A review of literature conducted in adults concluded that dynamic parameters should be used preferentially over static parameters to predict fluid responsiveness in critically ill patients.[2,9-11] Dynamic parameters measure changes in the circulation that due to cardiopulmonary interaction. Positive pressure ventilation induces a cyclical variation in LV preload, in turn in LV SV. This variation is more pronounced in hypovolemic state, i.e., when LV operates on the steep portion of the Frank–Starling curve.[12,13] At the flat portion of the curve, the ventilation induced changes in LV preload and in turn LV SV are minimal.

Over the last decade, several dynamic parameters have been investigated in the adult population. They are found to be very accurate and reliable in predicting volume responsiveness, so is their clinical utility. Though extensive literature is lacking, investigators have failed to translate the utility of most of these dynamic parameters in paediatric patients. Hence, we conducted this study to evaluate the usefulness of dynamic parameters such as Vpeak and dIVC in paediatric patients, which have not been investigated extensively.

A study was conducted in critically ill Intensive Care Unit paediatric patients to assess whether ΔVpeak could predict fluid responsiveness in ventilated children.[14] A total of 26 patients were studied, in which all patients received a fluid challenge of crystalloid or colloid around 20 ml/kg and transthoracic ECHO was used to measure the study parameters. Other parameters studied were CVP, pulse pressure variation (PPV) and systolic pressure variation (SPV). They concluded that ΔVpeak predicted the effects of VE better than PPV, and SPV. A threshold value of 12% showed sensitivity, specificity, positive predictive value and negative predictive value of 81%, 86%, 93% and 67%, respectively. They opined that the low predictive value of PPV and SPV could be because of the higher arterial compliance of children, which might have absorbed and nullified the respiratory variations observed in left ventricular SV.[15,16] They concluded the dynamic central measurements of fluid responsiveness were better indicator of fluid responsiveness in the paediatric population.

Similar studies were conducted in anaesthetised and mechanically ventilated children to detect the ability of various dynamic parameters to assess the volume responsiveness.[8,17] They compared CVP, ΔVpeak, PPV, pleth variability index and dIVC. It was concluded that ΔVpeak with a threshold value of 10–11% is both sensitive and specific for fluid responsiveness as compared to other dynamic parameters studied.

Evidence for dynamic studies of fluid responsiveness are lacking in Indian population. We studied the effect of fluid challenge on anaesthetised and mechanically ventilated children using a fluid challenge of 10 ml/kg of crystalloid. We compared VE-induced changes in ΔVpeak with SVI and found a threshold value for ΔVpeak of 12.2% with sensitivity, specificity, positive predictive value and negative predictive value of 100%, 94%, 96% and 100% respectively. Our study was in correlation with the above study, but we used a fluid challenge of 10 ml/kg of crystalloid as it was our unit policy. There is no consensus regarding the volume of fluid challenge that has to be administered, we have chosen an adequate and safe volume of 10 ml/kg.

Respiratory changes in IVC diameter is useful in predicting fluid responsiveness in adult patients.[7,18] It was found that a threshold value of 12–18% of dIVC allowed distinction between R and NR. Similar studies in paediatric population showed conflicting results.[17,19] Our study was conducted in paediatric anaesthetised patients with a fluid challenge of 10 ml/kg of crystalloid. We observed that a threshold value of dIVC 23.5% allowed discrimination between R and NR with sensitivity, specificity, and positive predictive value and negative predictive values of 91%, 89%, 92% and 89%, respectively. Further study would be required to investigate the behaviour of major systemic veins with respect to volume status in the paediatric population.

The advantage of dIVC is that it is non-invasive and can be performed easily as compared to technically challenging parameter like Vpeak. However, factors like raised intra-abdominal pressure may interfere with its predictability.

Our study had several limitations. ΔVpeak is affected by the tidal volume, the HR/ventilatory frequency ratio and presence of any arrhythmias. We aimed to maintain HR/ventilatory ratio of >4 in all patients. Option for superimposition of the ventilatory cycle on ultrasound monitor was not available; respiratory cycle was timed by visual monitoring of excursion of the ventilator bellow. However, it was timed to precision. ΔVpeak and dIVC are not reliable when spontaneous breaths are present. Transthoracic ECHO is rather more suitable in a critical care setting than in operation suite because of technical difficulty. However, esophageal Doppler can be useful in this context, especially to assess the volume status per-operatively. In the presence of raised intra-abdominal pressure reliability of dIVC is questionable. Collapsibility index of superior vena cava (SVC) measured by transesophageal ECHO may provide better information on volume status in this scenario as SVC is subjected directly to the effects of phasic changes in intrathoracic pressure during mechanical ventilation.

CONCLUSION

Respiratory variation in aortic flow peak velocity (ΔVpeak) and inferior vena cava distensibility index (dIVC) are reliable indices of fluid responsiveness in children.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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