Original Article

Goal-directed fluid therapy using transoesophageal echocardiographic inferior venacaval index in patients with low left ventricular ejection fraction undergoing major cytoreductive surgery: A clinical trial

ABSTRACT

Background and Aims: This study aims to trans oesophageal echo cardiographically (TOE) measure inferior venacava diameter (IVCD) during inspiration and expiration in poor left ventricular ejection fraction (LVEF) patients undergoing cytoreductive oncosurgery, to ascertain if any correlation exists between, caval index (DeltaIVCD), and stroke volume variation (SVV), and to compare DeltaIVCD-guided versus SVV-guided fluid therapy.

Methods: In this prospective, parallel group, interventional study, seventy American Society of Anesthesiologists-III patients, aged 30-75 years, weighing 40-90 kg, with LVEF ≤40% undergoing cytoreductive surgery were included and randomised to group-D (DeltaIVCD-guided fluid therapy) and group-S (SVV-guided fluid therapy). Patients with oesophageal lesions were excluded. After standard endotracheal anaesthesia, arterial and internal jugular vein catheters were placed. A TOE probe was inserted in the interventional group-D. Quantification of IVCD respiratory variations was done. Heart rate (HR), arterial oxygen saturation (SPO_2), mean arterial pressure, end tidal carbondioxide ($EtCO_2$), central venous pressure, SVV, IVCD, and urine output (UO) were recorded every 30 min. Post-operative arterial blood gas analysis, lung-ultrasound, chest-radiograph, and serum creatinine were done.

Statistical Analysis: Pearson's correlation coefficient as measure of strength of linear relationship, calculation of regression equation, and unpaired *t*-test for normally distributed continuous variables were used.

Results: A positive correlation between DeltaIVCD and SVV ($r = 0.751$) was observed. A regression equation was obtained for SVV (SVV = [0.317 × DeltaIVCD] + 5.877). Serum lactate, estimated glomerular filtration rate, HR, and UO were within normal limits in group-D. There was no pulmonary oedema.

Conclusion: DeltaIVCD-guided intravenous fluid therapy is valuable in low LVEF patients where tight fluid control is essential and any fluid overload may precipitate cardiac failure.

Key words: Cytoreduction surgical procedures; inferior vena cava; left ventricular function; stroke volume; transoesophageal echocardiography

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Introduction

Pre-operative chemotherapy with cardiotoxic drugs (adriamycin, cisplatin, trastuzumab, paclitaxel, 5-fluorouracil) causes reduction of left ventricular ejection fraction (LVEF) in several oncosurgical patients.[1] For real-time measurement of LVEF and cardiac output (CO), transoesophageal echocardiography (TOE) is immensely beneficial in patients with low LVEF undergoing non-cardiac surgery,[2] including cytoreductive surgery. Tailored peri-operative haemodynamic management, though challenging in such patients, is the key to improving outcomes due to propensity for cardiac failure with any fluid overload where clinical and vital signs are unreliable predictors of fluid responsiveness. Static indices of preload assessment such as central venous pressure (CVP), left ventricular end diastolic area (LVEDA), and pulmonary capillary wedge pressure (PCWP) have scant value in determining which patient will respond to intravenous (IV) fluid bolus by increasing his stroke volume.[3,4] Dynamic indices like pulse pressure variation (PPV), stroke volume variation (SVV),[5] inferior venacava diameter (IVCD) variation,[6] and aortic blood flow are better predictors of fluid responsiveness.

Among the invasive IV fluid guiding monitors CVP and SVV, SVV is considered superior since it predicts the reaction of stroke volume to small boluses of fluid loads.[5] Both IVCD and its variation (DeltaIVCD/caval index) are reasonably accurate, non-invasive indicators of intravascular fluid volume status in mechanically ventilated patients, conveniently measured intra-operatively byTOE (along with LVEF and CO).

The rationale behind this study was to determine whether DeltaIVCD was useful in guiding intra-operative fluid therapy in low LVEF patients, since a review of current literature did not yield any clinical study providing this information. The primary outcome measure was assessing the correlation between DeltaIVCD and SVV. The secondary outcome measures were CVP, HR and MAP measured at specific time-points and post-operative serum lactate, eGFR, B-lines on lung ultrasound and chest radiographic interstitial infiltrates used to compare DeltaIVCD and SVV-guided IV fluid therapy in low LVEF patients.

Methods

This prospective, interventional, single-centric, randomised clinical trial (registered with the Clinical Trial Registry of India; CTRI/2017/03/008200; acronym TEELEF-trial) was conducted after approval from the Institutional Review Board of a tertiary care oncology hospital and written informed consent from all patients. Seventy American Society of Anesthesiologists (ASA) physical status III female patients, aged 30–75 years, weighing 40–90 kg, with LVEF ≤40% (lower cut off value being 24%), and undergoing elective cytoreductive surgery for ovarian cancer were included. Exclusion criteria comprised positive history of oesophageal malignancy, surgery, varices, diverticuli, or failed radial artery cannulation. The first patient was enrolled in March 2017. The trial ended in May 2018 after the requisite number of cases was successfully completed. The patients were randomised into two groups Group-S (SVV-guided fluid therapy) and Group-D (Delta IVCD-guided fluid therapy) by simple computer generated randomisation. The method of concealment was sequentially numbered, sealed opaque envelopes.

After pre-medicating all patients with midazolam (0.05 mg/kg), anaesthesia was induced with IV fentanyl (2 µg/kg) and IV etomidate (0.2–0.3 mg/kg) till loss of eyelash reflex. Endotracheal intubation was facilitated by IV vecuronium (0.1 mg/kg). Invasive monitoring included arterial [for invasive blood pressure (IBP) and SVV] and internal jugular vein catheterisation. Vigileo™ (Edwards Lifescience, USA) CO monitor, with a FloTrac sensor upgraded to the latest fourth generation algorithm (Software Release Version No: VO4.00, PIC V2.0), provided SVV values.

In group-D patients, after thorough nasogastric tube suctioning, a TOE probe (E Saote; via di Caciolle 15 Firenze-Italia) was laryngoscopically inserted to obtain a midoesophageal four-chamber cardiac view. A bicaval view of the right atrium (RA) was obtained by rotation to 90–100° and slight retroflexion when required, to visualise the IVC in its long axis at the cavoatrial junction [Figure 1]. The CVP line was flushed with a fluid bolus by pulling the pigtail (Intraflo® flush) attached to the transducer (Transpac IV; ICU Medical; San Clemente). Visualisation of a turbulent gush of fluid emanating from the superior venacava (SVC) into the

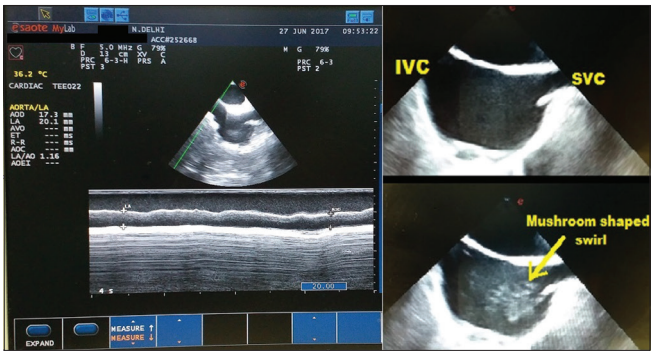

Figure 1: Left side: Transoesophageal echocardiographic image showing the inferior venacava (IVC) in the bicaval view and also as a linear image in the M-mode; right side: mushroom sign to verify CVP catheter placement in superior venacava

RA (mushroom sign) served as a confirmatory test for two things: first, identification of SVC from IVC and, second, correct placement of the CVP line [Figure 1]. The maximum and minimum IVCD ($IVCD_{max}$ and $IVCD_{min}$) was measured during one respiratory cycle from the M-Mode tracing taken at the cavo-atrial junction after ECG synchronisation to coincide with the end of T-wave. Tidal volume during IVCD measurement was fixed at 8 ml/kg body weight, no positive end expiratory pressure (PEEP) was applied, and sinus rhythm was ensured. The caval index (DeltaIVCD) for guiding IV fluids was calculated as

$$\frac{IVCD_{max} - IVCD_{min}}{IVCD_{min}}$$

Maintenance of anaesthesia included oxygen (40%) in medical air, 1–1.5% end tidal sevoflurane, IV morphine 0.1 mg/kg, hourly IV fentanyl boluses (0.3 μg/kg), bispectral index-guided propofol infusion, and peripheral nerve stimulator-guided vecuronium infusion. Core temperature was maintained above 35.5°C using fluid-warmers and convective warming blankets. Serial recording of heart rate (HR), MAP, oxygen saturation (SPO_2), urine output (UO), CVP, SVV and IVCD was performed at baseline (5 min post-endotracheal intubation) and every 30 min thereafter. Blood loss was replaced with equivalent volumes of packed red blood cells (PRBCs), keeping "haemoglobin 10 g%" as the blood transfusion target. Rescue drugs included dobutamine (for ≥20% fall in CO), noradrenalin (for ≥20% fall in MAP), nitroglycerine (for ≥20% rise in MAP), and IV esmolol bolus (0.5 mg/kg for ≥20% increase in HR) after considering pain relief and anaesthetic depth. Titration of these three drug infusions helped us maintain haemodynamic stability. Warm isotonic physiological crystalloid (Plasmalyte™) was infused guided by the DeltaIVCD in Group-D. For DeltaIVCD values <12, background crystalloid infusion rate was fixed at 100 ml/h which was increased to 250 ml/h for DeltaIVCD range 12-18. A colloid bolus (250 ml Voluven™) was infused over 10 min whenever DeltaIVCD rose above 18 intra-operatively. In Group-S, crystalloid transfusion rates were 100 ml/h for SVV ≤10 and 250 ml/h for SVV range 11–18. A bolus of 250 ml colloid over 10 min was infused whenever SVV crossed 18 intra-operatively.

The urinary bladder was catheterised and emptied after anaesthetic induction. Low UO (<0.5 ml/kg/hr) was treated with IV furosemide (5 mg) after considering volume status, cardiac output and blood pressure. A post-operative arterial blood gas (ABG) analysis, serum creatinine, chest radiograph, and lung ultrasound were performed in all patients. IVCD was measured during inspiration and expiration utilising TOE and DeltaIVCD was calculated.

It was ascertained whether any correlation existed between DeltaIVCD and SVV. A regression equation was obtained for any significant correlation. It was analysed if quantification of respiratory IVCD variation (DeltaIVCD) can guide IV fluid administration in these patients and outcomes were compared with SVV-guided IV fluid therapy.

For tests of association using bivariate correlations, a moderate correlation between DeltaIVCD and SVV is considered meaningful. To detect a moderate correlation ($r = 0.40$), a sample of 37 analysable subjects will provide 80% power to discover that the correlation is significantly different from there being no correlation at the 0.05 level. Allowing for dropouts, we selected a sample size of 40 patients for group-D where the correlation between the two measures of fluid responsiveness was analysed. Through a pilot study of five patients per group, the mean serum lactate levels were found to be 2.3 in Group-S and 1.4 in Group-D. The sample size was calculated as 28 patients per group with a power of 90%, at α of 0.05 where the standard deviation (SD) of groups was 0.4 and 0.24, respectively. Allowing for dropouts, we took $n = 30$ patients in Group-S.

Statistical testing was conducted with the Statistical Package for the Social Science System (version SPSS 21.0 Chicago SPSS Inc.). Continuous variables were expressed as mean ± SD, whereas categorical variables were expressed as absolute numbers and percentage. The unpaired *t*-test and Chi-square test were used for normally distributed continuous variables and categorical variables respectively. A *P* value of ≤0.05 was considered statistically significant. Pearson's correlation coefficient (*r*) was used as a measure of strength of linear relationship between DeltaIVCD and SVV. A regression equation was derived after obtaining a significant correlation.

Results

The CONSORT flow diagram [Figure 2] depicts the flow of participants. Demographic variables reveal that both groups were comparable with respect to age, height, weight, ASA status, and LVEF [Table 1].

The $IVCD_{max}$, $IVCD_{min}$, HR, MAP, and UO recorded at various time points (baseline, 30 min, 60 min, 90 min, 120 min, and 150 min post-endotracheal intubation) in both the groups are depicted in Figure 3, whereas DeltaIVCD, SVV, and CVP at the same timepoints (only Group D) are depicted in Figure 4.

DeltaIVCD and SVV show a positive correlation, and any rise in DeltaIVCD was accompanied by a corresponding rise in SVV values as well [Figure 4]. Percent change in DeltaIVCD from

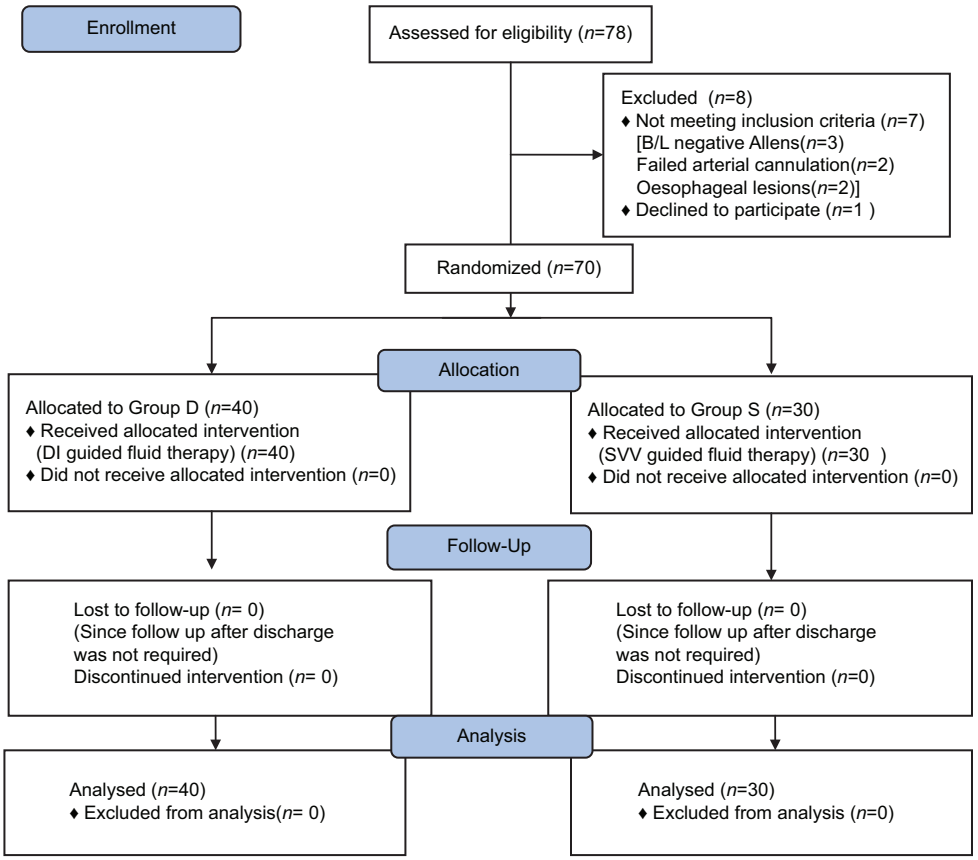

Figure 2: CONSORT diagram depicting flow of participants

baseline and percent change in SVV from baseline showed a statistically significant positive correlation ($r = 0.751$; P value <0.001; Table 2). The regression equation derived from this correlation is

$$SVV = [0.317 \times DeltaIVCD] + 5.877 \ (R^2 = 0.586; t = 7.337; P < 0.001)$$

LVEDA measured at beginning of surgery was 1811.93 ± 291.68 (mean ± SD) with 1290 and 2432 mm^2 as the minimum and maximum dimensions. The mean blood loss, PRBCs, and fresh frozen plasma units transfused and the mean colloid and crystalloid bottles infused have been tabulated [Table 1]. Mean serum lactate value from pre-operative baseline ABG was 1.06 ± 0.22 and 1.05 ± 0.19 mg% in Group-D and Group-S, respectively, whereas the post-operative values were 1.39 ± 0.58 mg% in Group-D and 2.01 ± 0.62 mg% in Group-S, respectively. Both pre-operative and post-operative serum creatinine ranged between 0.2 and 1.2 mg% in both groups. For group-D patients, the mean pre-operative estimated glomerular filtration rate (eGFR; calculated by entering the gender, age, race, and serum creatinine values into the QxMDeGFR calculator; MDRD formula) was 109.13 ± 0.76 ml/min/1.73 m^2 and the mean post-operative values were 100.22 ± 0.94 ml/min/1.73 m^2.The HR could be maintained at baseline ±20% in 36/40 patients

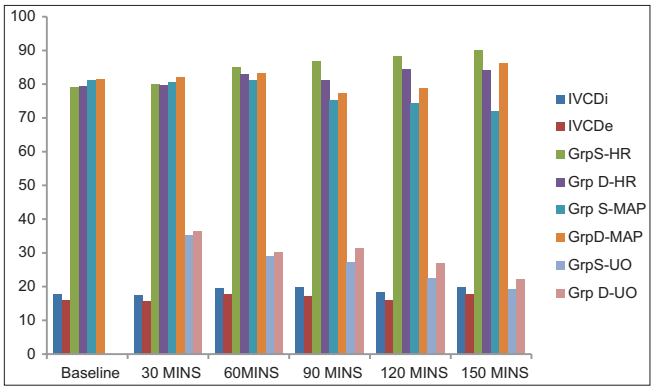

Figure 3: The IVCD maximum/expiratory (IVCDe; mm), IVCD minimum/inspiratory (IVCDi; mm), HR (beats/min), MAP (mmHg), and UO (ml) recorded at various time points (baseline, 30 min, 60 min, 90 min, 120 min, and 150 min post-endotracheal intubation); HR in Group S (Grp S-HR), HR in Group D (Grp D-HR), MAP in Group S (Grp S-MAP), MAP in Group D (Grp D-MAP), UO in Group S (Grp S-UO), and UO in Group D (Grp D-UO);Grp S-HR and Grp D-HR at 150 min and Grp S-MAPand Grp D-MAP at 150 min showed a statistically significant difference ($P = 0.04$ and $P = 0.01$, respectively)

with DeltaIVCD-guided fluid therapy alone whereas four patients required the rescue drug esmolol (20 μg boluses). In 8/30 group-S patients, esmolol was administered for HR control. In Group-D, the mean hourly UO was 0.79 ml/kg body weight in 35/40 patients with fluid therapy alone whereas five patients required 10 mg furosemide bolus as rescue drug. In Group-S,

Table 1: The demographic variables and other parameters

Demographic parameter	Group	Mean±SD	Median	Min-max	*P*
Age (years)	SVV	53.5±11.56	53.00	30-73	0.89
	DeltaIVCD	54.00±12.38	54.00	30-75	
Weight (kg)	SVV	64.77±10.3	64.00	47-89	0.87
	DeltaIVCD	63.65±10.80	64.00	44-90	
Height (cm)	SVV	156.5±6.01	155.00	145-171	0.86
	DeltaIVCD	157.30±5.82	156.00	146-174	
BMI (kg/m^2)	SVV	25.53±3.22	24.99	19.1-36.44	0.65
	DeltaIVCD	25.64±3.41	25.13	18.99-36.65	
LVEF (%)	SVV	34.18±3.40	34	24-39	0.76
	DeltaIVCD	33.96±3.57	34	23-39	
Blood loss (L)	SVV	2.5±0.4	2.6	1-4.5	0.79
	DeltaIVCD	2.4±0.5	2.5	1-5	
PRBC (*n*)	SVV	2.29±1.03	2.2	1-5	0.86
	DeltaIVCD	2.25±1.37	2.00	1-6	
FFP (*n*)	SVV	1.18±1.10	1	0-3	0.76
	DeltaIVCD	1.17±1.07	1	0-3	
Colloid (*n*)	SVV	1.8±1.05	2.00	1-3	0.84
	DeltaIVCD	2.10±1.01	2.00	1-4	
Crystalloid (*n*)	SVV	4.58	4	1-6	0.45
	DeltaIVCD	5.69	5	2-8	
Propofol (ml) (4 mg=1 ml)	SVV	98.4±5	97	70-115	0.62
	DeltaIVCD	97.1±6	97	69-117	
S. lactate (mg%) (post op.)	SVV	2.01±0.62	1.9	0.8-3	0.09
	DeltaIVCD	1.39±0.58	1.3	0.5-1.8	
eGFR (post op.) (ml/min/1.73 m^2)	SVV	98.32±0.89	98.1	89.2-118.9	0.61
	DeltaIVCD	100.22±0.94	100.1	91.4-120.1	

SD=Standard deviation, SVV=Stroke volume variation, DeltaIVCD=Delta Inferior Vena Cava Diameter, PRBC=Packed red blood cells, *n*=Number of bottles, FFP=Fresh frozen plasma, eGFR=Estimated glomerular filtration rate

Table 2: Correlation between change in DeltaIVCD (Delta Inferior Vena Cava Diameter) from baseline and change in SVV (stroke volume variation) and CVP (central venous pressure), respectively, at specific time points

Time	Pearson's correlation coefficient between SVV and DeltaIVCD and CVP and DeltaIVCD		
		SVV	CVP
At time point 2	*r*	0.653	-0.309
	P	<0.001	0.053
At time point 3	*r*	0.542	-0.204
	P	<0.001	0.206
At time point 4	*r*	0.739	-0.419
	P	<0.001	0.007
At time point 5	*r*	0.751	-0.637
	P	<0.001	<0.001
At time point 6	*r*	0.750	-0.586
	P	<0.001	<0.001

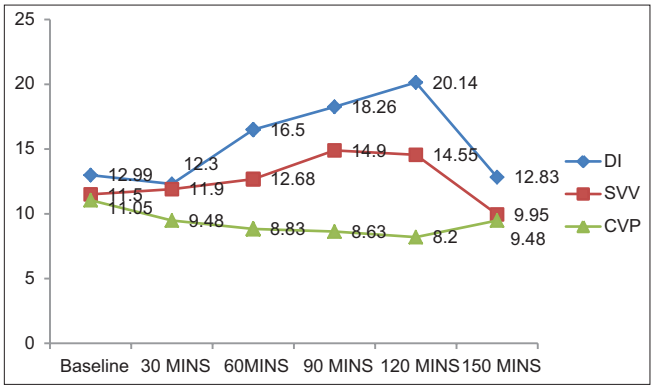

Figure 4: The DeltaIVCD, SVV, and CVP at various time points (baseline, 30 min, 60 min, 90 min, 120 min, and 150 min post-endotracheal intubation) (DeltaIVCD = delta inferior venacava diameter; SVV = stroke volume variation; CVP = central venous pressure)

the mean hourly UO was 0.51 ml/kg with nine patients requiring furosemide rescue. None of the Group-D patients exhibited interstitial infiltrates in post-operative chest radiographs and their post-operative lung USG showed less than three B-lines. One patient in Group-S showed four B-lines in bilateral lung bases.

Discussion

IVC is a thin-walled, compliant blood vessel, whose blood volume and diameter dynamically changes with the body's IVfluid-volume status. Lorsomradee *et al*.[7] observed a strong correlation between TOE-derived IVCD (at cavoatrial junction) andCVP for CV*P* values ≤11 mmHg (r = 0.801) in their prospective study, involving 70 cardiac surgical patients.

Arthur *et al*.[8] reported similar findings ($n = 95$, $r = 0.860$). Unfortunately, IVCD just like CVP and LVEDA is a static indicator of fluid responsiveness.

IVC diameter varies with tidal respiration, the extent of respiratory variation depending on intra-thoracic and intra-abdominal pressures, CVP and IVC compliance. The ability of abdominal IVC to dilate during tidal ventilation, when intra-thoracic pressure increases more than abdominal pressure, in mechanically ventilated patients is a reflection of the capacity of the IVC to receive more fluid volume (preload reserve present), akin to a conserved compliance.[9] In mechanically ventilated patients, respiratory variations in abdominal IVCD are quantified by Distensibility Index $\left(\frac{IVCD_{max} - IVCD_{min}}{IVCD_{min}}\right)$ while respiratory variations in thoracic IVCD are quantified by DeltaIVCD $\left(\frac{IVCD_{max} - IVCD_{min}}{IVCD_{min}}\right)$. For both these portions of IVC, $IVCD_{max}$ represents the maximum IVCD during a respiratory cycle whereas $IVCD_{min}$ denotes the minimum IVCD during the same cycle measured in M-Mode.[2] $IVCD_{max}$ falls in the inspiratory phase for abdominal IVC and expiratory phase for thoracic IVC, whereas $IVCD_{min}$ falls in the expiratory phase for abdominal and inspiratory phase for thoracic IVC. Absence of respiratory IVCD variations indicates an adequately filled intravascular compartment not requiring volume expansion. Exaggerated respiratory variations, accompanied by signs of circulatory insufficiency, indicate hypovolaemia, and requirement of IVfluids.[6,10,11] DI $\geq$18 indicates that the patient is likely to respond to vascular filling by increasing his CO, with a positive predictive value (PPV) of 93% and a negative predictive value of 92%. DeltaIVCD, just like DI and SVV, is a dynamic indicator of fluid responsiveness.[6,12]

The point of entry of the IVC into the right atrium (the site chosen by us) is the best site for IVCD measurement as per a recent study (Naghipour *et al*.[13]) They have chosen, the 2-dimensional long axis mid-esophagealbicaval view for IVCD measurement using TOE probe just like us. SVC collapsibility seen on TOE may be a better predictor of fluid responsiveness than IVC variability as per Vignon *et al*.[14] who have compared IVCD taken by TTE with SVCD taken by TOE. A study comparing the IVCD and SVCD in the bicaval TOE view is required to finally dismiss this controversy. Since the site of SVCD measurement is the bicaval view,[15,16] it follows that IVCD measured from the bicaval TOE view would give comparable results with SVCD measured from the same view. Both IVC and SVC are intrathoracic in this view where they are seen joining the right atrium.

Intra-operative utility and safety of TOE has been established previously for cardiac surgery and recently for non-cardiac surgery as well.[2,14,17,18] We studied a novel TOE-derived parameter, DeltaIVCD, which was hitherto not used intra-operatively. Arthur and Lorsomradee had measured IVCD using TOE in ICU patients,[8,9] and hence, we anticipated that TOE could provide us with the DeltaIVCD (a derivative of IVCD from M-mode tracing) as well.

Several studies in critical care setting conclude that transthoracic echocardiography (TTE)-derived DI is a very good (area under receiver operator curve; AUROC >0.8) to excellent (AUROC 0.9–1) diagnostic indicator for fluid responsiveness in mechanically ventilated septic patients.[12,15,19,20] Lujan *et al*.[19] observed that out of 11 patients with DI <18%, 10 (90.9%) did not respond to fluid challenge. We too avoided a fluid bolus for DeltaIVCD <18%. Barbier *et al*.[11] used 18% as cutoff and reported 90% sensitivity and 90% specificity for DI in detecting fluid responsiveness (AUROC 0.91). Moretti and Pizzi[21] reported 70% sensitivity and 100% specificity for DI keeping 16% as cutoff (AUROC 0.90) in 29 ICU patients with subarachnoid haemorrhage. Macharedelgado*et al*.[22] reported 100% sensitivity but only 53% specificity for DI taking 12% as cut off (AUROC 0.81) whereas AUROC for SVV by Vigileo was only 0.57 in the same studyon 25 ICU sepsis patients.

The obstacle in using DeltaIVCD intra-operatively was that unfortunately, subcostal TTE cannot be employed intra-operatively when the surgical field coincides with site of ultrasound probe placement. However, this is the critical phase when efficient IV fluid management is most required. Circumventing this problem we filled the lacuna at this crucial point by utilising TOE to provide intra-operative DeltaIVCD values which is a first. The short intra-operative period (4-5 h) is conducive to contiguous TOE monitoring. Also, TOE is *per se* indicated in low LVEF patients for intra-operative LVEF monitoring and detecting fresh regional wall motion abnormalities.[13,14,23] An additional benefit is intraoperative confirmation of CVP catheter-tip position from the bicaval view used for IVCD measurement.

SVV-based GDT for major orthopaedic surgery,[17] decreases the required intra-operative fluids, maintains intra-operative hemodynamic stability, and improves peri-operative gastrointestinal function. Cannessen *et al*.[5] compared SVV with delta pulse pressure to monitor fluid responsiveness in 25 mechanically ventilated patients undergoing coronary artery bypass grafting and found a sensitivity of 82% and specificity of 88% with SVV. In a meta-analysis of 568 patients (OT/ICU) from 23 studies, SVV was correlated to fluid responsiveness with a pooled diagnostic odds ratio (DOR) of 18.4 (pooled sensitivity 0.81; specificity 0.80).[18] Pooled DOR for respiratory changes in IVC in mechanically

ventilated patients ($n = 116$) was 30.8 and that for spontaneously breathing patients ($n = 40$) was 13.2 as per a meta-analysis of 8 studies (using TTE) by Zhang *et al*.[20]

We found a strong correlation between DeltaIVCD and SVV and better secondary outcomes (serum lactate, UO, eGFR) with DeltaIVCD as compared to SVV which correlates with the pooled DOR of 18.4 for SVV and 30.8 for DI in these studies. Currently, there is no publication directly comparing SVV with DeltaIVCD intra-operatively for fluid responsiveness. After finding a strong positive correlation between DeltaIVCD and SVV in low LVEF patients with high potential for hemodynamic complications, we derived a regression equation for estimating corresponding SVV values from DeltaIVCD, without having to introduce invasive arterial lines.

Regression coefficients represent the mean change in the response variable per unit change in the predictor variable (DeltaIVCD in our case) holding other predictors in the model constant. R^2 (coefficient of determination) denotes how much variance of the data is "explained" by the regression model. ($R^2 > 0.4$ and t-ratio >2 are considered statistically significant) The regression equation where SVV is the dependent variable (SVV = [0.317 × DeltaIVCD] + 5.877) gives $R^2 = 0.59$, $t = 7.34$, and $P < 0.001$ (statistically highly significant).

Fluid overload results in tissue oedema causing poor wound healing, wound infection, and pressure ulcers post-operatively.[11,17,24,25] Oedema of visceral organs compromises their functioning. Cerebral oedema may produce post-operative cognitive dysfunction and delirium. Absence of any clinical signs of fluid overload or pulmonary oedema in post-operative radiographs indicates low probability of circulatory overload. Although, splanchnic oedema can occur despite absence of peripheral or pulmonary oedema but the usual cause is right sided failure and not left sided failure. Since our patients had a low LVEF we monitored pulmonary oedema. PRBCs were used to replace blood loss instead of whole blood to prevent fluid overload.

Increased serum lactate is a marker for inadequate tissue perfusion, anaerobic respiration, and hypovolaemic shock.[26] Normal serum lactate concentration in unstressed patients is 0.5–1 mmol/l. In critical illness/surgical stress, lactate concentrations <2 mmol/l are considered normal. Post-operative serum lactate levels (1.39 ± 0.58 mg%) and PaO_2/FiO_2 oxygenation index in Group-D patients were within normal range whereas Group-S exhibited elevated lactate levels. UO too was maintained between 0.5 and 1 ml/kg/h in all patients and the eGFR was 100.22 ± 0.94 ml/min/1.73 m^2 indicating that IV fluids administered keeping DeltaIVCD as the goal provided adequate tissue perfusion in our high-risk elective surgical patients. Ours is the first reported study evaluating the usefulness of DeltaIVCD-guided fluid therapy intra-operatively, in patients with low LVEF, where TOE probe placement is already indicated to monitor the real time LVEF among others.

This study is generalizable to all surgical patients with compromised left ventricular function. As per one study (Taniguchi *et al*.)[27], although IVCD varies with patient's body surface area (BSA), collapsibility index (and DeltaIVCD as an extrapolation) is independent of BSA. The optimal cutoff points of IVCDmax were 21 mm and 17 mm for patients with larger and smaller BSAs respectively. However, the cutoff point of IVC collapsibility was not influenced by the difference of BSA.

Limitations of this study include the fact that IVC may be dilated in certain subsets of population like athletes, especially swimmers (23 mm versus 13 mm in control group) even though their RAP is normal.[28] Similar IVC dilatation without increased RAP is observed in young adults with vasovagal syncopal attacks.[29] Suboptimal functioning/dampening of invasive catheters/transducers and inter observer variation in acquisition and interpretation of sonographic IVCD measurements affect the accuracy of measurements.

Conclusion

DeltaIVCD-guided IV fluid therapy is valuable in the subset of patients with LVEF ≤40%, where tight fluid control is crucial and any fluid overload may precipitate cardiac failure.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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