

Research Article

POCUS Assessment of Fluid Responsiveness in Patients Undergoing Major Surgery

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Received: 18.03.26, Revised: 21.04.26, Accepted: 27.05.26

ABSTRACT

Background: Accurate prediction of fluid responsiveness is important during major surgery to optimise haemodynamics and avoid unnecessary fluid administration. This study evaluated point-of-care ultrasonography (POCUS) for predicting fluid responsiveness.

Methods: This prospective observational study included 90 patients undergoing major surgery. IVC respiratory variation and LVOT-VTI were measured before and after a standardised fluid challenge. Patients were classified as responders or non-responders based on change in stroke volume.

Results: Of 90 patients, 52 (57.8%) were responders. Responders had greater IVC respiratory variation ($21.8 \pm 6.4\%$ vs $13.2 \pm 5.1\%$, $p < 0.001$), lower baseline LVOT-VTI (15.2 ± 2.6 vs 18.1 ± 2.9 cm, $p < 0.001$), and greater change in LVOT-VTI ($21.4 \pm 7.6\%$ vs $4.3 \pm 3.1\%$, $p < 0.001$). IVC variation $> 18\%$ predicted fluid responsiveness with an AUC of 0.84, sensitivity of 82.7%, and specificity of 78.9%. LVOT-VTI ≤ 16.5 cm yielded an AUC of 0.79, sensitivity of 76.9%, and specificity of 73.7%.

Conclusion: POCUS-derived IVC variation and LVOT-VTI showed good predictive ability for fluid responsiveness and may help guide individualised perioperative fluid therapy.

Keywords: POCUS, Fluid Responsiveness, IVC, LVOT-VTI, Major Surgery.

INTRODUCTION

Optimal perioperative fluid management is an essential component of anaesthetic care in patients undergoing major surgery. Preoperative fasting, anaesthetic-induced vasodilatation, positive-pressure ventilation, surgical blood loss, and redistribution of intravascular fluid can produce substantial alterations in circulating volume and cardiac preload.[1] Intravenous fluids are therefore frequently administered to maintain haemodynamic stability, cardiac output, and tissue perfusion. However, excessive fluid administration may result in fluid overload and has been associated with organ dysfunction, postoperative complications, and increased mortality.[2,3] The haemodynamic benefit of fluid administration depends on whether an increase in preload produces a meaningful increase in stroke volume or cardiac output, a phenomenon termed fluid responsiveness.[1,4] Importantly, hypotension or suspected hypovolaemia does not necessarily indicate that a patient will respond to volume expansion.

Administration of fluid to a non-responsive patient may increase intravascular and interstitial volume without producing a significant improvement in cardiac output. Identifying fluid responsiveness before administering a fluid bolus is therefore important for individualising perioperative fluid therapy.[1,4] Traditionally, fluid therapy has been guided by clinical and static haemodynamic variables such as heart rate, arterial blood pressure, urine output, central venous pressure, and pulmonary artery occlusion pressure. However, static measures of cardiac preload, particularly central venous pressure, have limited ability to predict the response to fluid administration.[5] Dynamic indices such as pulse pressure variation (PPV) and stroke volume variation (SVV) have consequently gained importance for assessing preload dependence.[6,7] Although these parameters can predict fluid responsiveness, their reliability may be influenced by tidal volume, cardiac rhythm, mechanical ventilation, patient positioning, and surgical

conditions.[6,8] In this context, point-of-care ultrasonography (POCUS) has emerged as a promising bedside method for perioperative haemodynamic assessment. POCUS enables rapid and repeatable evaluation of cardiac function, venous filling, and blood flow without the routine requirement for advanced invasive haemodynamic monitoring.[9] Respiratory variation in inferior vena cava (IVC) diameter is among the most frequently investigated ultrasound-derived parameters for assessing fluid responsiveness. Zhang et al. demonstrated that IVC respiratory variation could predict the haemodynamic response to volume expansion in mechanically ventilated patients undergoing surgery.[10] Nevertheless, the diagnostic performance of IVC-derived indices may vary with respiratory status, ventilatory settings, intra-abdominal pressure, and right ventricular function.[11]

POCUS also allows Doppler assessment of the left ventricular outflow tract velocity-time integral (LVOT-VTI). Changes in LVOT-VTI can serve as a surrogate for changes in stroke volume and may therefore provide a dynamic measure of preload responsiveness. VTI-based measurements have demonstrated promising ability to identify fluid-responsive patients under mechanical ventilation.[12] Similarly, changes in LVOT-VTI during the Trendelenburg manoeuvre have shown good predictive performance for fluid responsiveness in the operating room.[13]

The role of POCUS is particularly relevant during major surgery, where haemodynamic conditions may change rapidly and repeated decisions regarding fluid administration are required. However, the performance of ultrasound-derived parameters varies across clinical settings, and evidence in heterogeneous major surgical populations remains limited. Therefore, the present study was undertaken to assess the utility of POCUS-derived haemodynamic parameters in predicting fluid responsiveness in patients undergoing major surgery and to evaluate their potential role in guiding individualised perioperative fluid therapy.

MATERIALS AND METHODS

This prospective observational study was conducted in the Department of Anaesthesiology. The study was initiated after approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants before enrolment. A total of 90 patients aged 18–65

years, belonging to American Society of Anesthesiologists (ASA) physical status I–III and undergoing major elective surgery under general anaesthesia with controlled mechanical ventilation, were included in the study.

Study Groups

Following the standardised fluid challenge, patients were classified into two groups according to their haemodynamic response:

Group R (Responders): Patients demonstrating an increase of $\geq 15\%$ in stroke volume following the fluid challenge were classified as fluid responders.

Group NR (Non-responders): Patients demonstrating an increase of $< 15\%$ in stroke volume following the fluid challenge were classified as non-responders.

Inclusion Criteria

Patients aged 18–65 years, of either sex, belonging to ASA physical status I–III, undergoing major elective surgery under general anaesthesia with controlled mechanical ventilation, and requiring intraoperative assessment of volume status were included.

Exclusion Criteria

Patients with significant cardiac dysfunction, clinically important valvular heart disease, cardiac arrhythmias, severe pulmonary hypertension, right ventricular dysfunction, raised intra-abdominal pressure, severe renal or hepatic dysfunction, pregnancy, or haemodynamic instability requiring immediate resuscitation were excluded. Patients in whom an adequate ultrasonographic window could not be obtained were also excluded.

Preoperative Assessment and Anaesthetic Management

All patients underwent routine pre-anaesthetic evaluation, including medical history, physical examination, and relevant laboratory investigations. Standard preoperative fasting guidelines were followed. On arrival in the operating room, electrocardiography, non-invasive blood pressure, and pulse oximetry were instituted. Baseline heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure (MAP), and peripheral oxygen saturation were recorded. General anaesthesia was induced according to the institutional protocol. Following tracheal intubation, patients were mechanically ventilated using volume-controlled ventilation. Ventilatory parameters were maintained within clinically acceptable

ranges and kept unchanged during assessment of fluid responsiveness.

POCUS Assessment

Point-of-care ultrasonography (POCUS) was performed by an anaesthesiologist trained in perioperative ultrasonography. The inferior vena cava (IVC) was visualised using the subcostal approach. Maximum and minimum IVC diameters during the respiratory cycle were recorded, and IVC respiratory variation was calculated.

Focused transthoracic echocardiography was performed to measure the left ventricular outflow tract velocity-time integral (LVOT-VTI). Pulsed-wave Doppler recordings were obtained from the apical window, and the Doppler envelope was traced to determine LVOT-VTI. Measurements from consecutive cardiac cycles were averaged for analysis.

Fluid Challenge and Assessment of Fluid Responsiveness

After recording baseline haemodynamic and POCUS parameters, a standardised fluid challenge was administered intravenously. Interventions likely to significantly alter preload or cardiac output were avoided during this period whenever clinically feasible. Following the fluid challenge, heart rate, blood pressure, MAP, IVC parameters, and LVOT-VTI were reassessed using the same technique. The percentage change in stroke volume was calculated. Patients with an increase in stroke volume of $\geq 15\%$ were assigned to Group R, whereas those with an increase of $< 15\%$ were assigned to Group NR.

Outcome Measures

The primary outcome was the diagnostic performance of POCUS-derived parameters, particularly IVC respiratory variation and LVOT-VTI, in predicting fluid responsiveness. Secondary outcomes included changes in haemodynamic and POCUS parameters following fluid administration, comparison of these parameters between Group R and Group NR, and correlation of POCUS-derived indices with the percentage change in stroke volume.

Statistical Analysis

Data were analysed using [SPSS version 26]. Continuous variables were expressed as mean $\pm$ SD or median (IQR), depending on data distribution, while categorical variables were presented as frequency and percentage. Normality was assessed using the Shapiro–Wilk

test. Group R and Group NR were compared using the independent-samples t-test or Mann–Whitney U test, as appropriate. Pre- and post-fluid challenge measurements were compared using the paired t-test or Wilcoxon signed-rank test. Categorical variables were analysed using the Chi-square test or Fisher's exact test. Receiver operating characteristic (ROC) curve analysis was performed to determine the predictive performance of IVC respiratory variation and LVOT-VTI. Area under the curve (AUC) with 95% confidence interval was calculated, and optimal cut-off values were determined using the Youden index. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy were calculated. Pearson or Spearman correlation was used to assess the relationship between POCUS parameters and percentage change in stroke volume. A p-value < 0.05 was considered statistically significant.

RESULTS

A total of 90 patients were included, of whom 52 (57.8%) were classified as fluid responders and 38 (42.2%) as non-responders. The two groups were comparable with respect to age, sex, BMI, ASA physical status, baseline heart rate, and baseline MAP, with no statistically significant differences observed for these characteristics (all $p > 0.05$) (Table 1).

Following fluid challenge, responders demonstrated significant haemodynamic improvement. Heart rate decreased from 82.6 ± 10.8 to 78.2 ± 9.7 beats/min ($p = 0.012$), while SBP increased from 101.4 ± 10.6 to 113.2 ± 11.1 mmHg, DBP from 54.1 ± 7.2 to 60.9 ± 7.4 mmHg, and MAP from 69.8 ± 7.5 to 78.4 ± 7.1 mmHg (all $p < 0.001$). In contrast, changes in heart rate, SBP, DBP, and MAP among non-responders were not statistically significant (all $p > 0.05$) (Table 2, Figure 1).

Baseline POCUS parameters differed significantly between responders and non-responders. Responders had smaller maximum (1.63 ± 0.28 vs 1.82 ± 0.30 cm; $p = 0.003$) and minimum IVC diameters (1.28 ± 0.25 vs 1.58 ± 0.27 cm; $p < 0.001$), greater IVC respiratory variation ($21.8 \pm 6.4\%$ vs $13.2 \pm 5.1\%$; $p < 0.001$), and lower baseline LVOT-VTI (15.2 ± 2.6 vs 18.1 ± 2.9 cm; $p < 0.001$). The percentage change in LVOT-VTI was also substantially greater among responders ($21.4 \pm 7.6\%$ vs $4.3 \pm 3.1\%$; $p < 0.001$), whereas post-fluid LVOT-VTI was comparable between groups ($p = 0.511$) (Table 3).

For the overall cohort, fluid administration resulted in significant increases in maximum IVC diameter (+0.15 cm), minimum IVC diameter (+0.21 cm), and LVOT-VTI (+2.2 cm), together with a reduction in IVC respiratory variation by 5.5 percentage points (all $p < 0.001$) (Table 4).

ROC analysis demonstrated that IVC respiratory variation $>18\%$ predicted fluid responsiveness with an AUC of 0.84 (95% CI 0.75–0.92), sensitivity of 82.7%, specificity of 78.9%, and accuracy of 81.1%. Baseline LVOT-VTI ≤ 16.5 cm showed an AUC of 0.79 (95% CI 0.69–

0.88), with 76.9% sensitivity, 73.7% specificity, and 75.6% accuracy (Table 5, Figure 2).

Correlation analysis showed that percentage change in stroke volume was positively correlated with IVC respiratory variation ($r = 0.58$, $p < 0.001$) and most strongly with percentage change in LVOT-VTI ($r = 0.71$, $p < 0.001$). Baseline LVOT-VTI showed a significant inverse correlation ($r = -0.46$, $p < 0.001$), while baseline MAP demonstrated a weak inverse correlation ($r = -0.21$, $p = 0.047$). Age and BMI were not significantly correlated with change in stroke volume (Table 6, Figure 3).

Table 1. Baseline demographic and clinical characteristics of fluid responders and non-responders

Parameter	Responders (n=52)	Non-responders (n=38)	p-value	Statistical test
Age (years), mean $\pm$ SD	45.9 $\pm$ 12.1	48.1 $\pm$ 12.8	0.410	Independent t-test
Male, n (%)	31 (59.6)	21 (55.3)	0.681	Chi-square test
Female, n (%)	21 (40.4)	17 (44.7)		
BMI (kg/m ²), mean $\pm$ SD	24.7 $\pm$ 3.2	25.1 $\pm$ 3.4	0.568	Independent t-test
ASA I, n (%)	14 (26.9)	11 (28.9)	0.927	Chi-square test
ASA II, n (%)	28 (53.8)	19 (50.0)		
ASA III, n (%)	10 (19.2)	8 (21.1)		
Baseline heart rate (beats/min)	82.6 $\pm$ 10.8	80.9 $\pm$ 11.2	0.470	Independent t-test
Baseline MAP (mmHg)	69.8 $\pm$ 7.5	72.6 $\pm$ 8.1	0.094	Independent t-test

Table 2. Changes in haemodynamic parameters following fluid challenge

Parameter	Responders Pre-fluid	Responders Post-fluid	p-value	Non-responders Pre-fluid	Non-responders Post-fluid	p-value
Heart rate (beats/min)	82.6 $\pm$ 10.8	78.2 $\pm$ 9.7	0.012	80.9 $\pm$ 11.2	79.8 $\pm$ 10.6	0.418
SBP (mmHg)	101.4 $\pm$ 10.6	113.2 $\pm$ 11.1	<0.001	105.2 $\pm$ 11.4	108.1 $\pm$ 10.8	0.121
DBP (mmHg)	54.1 $\pm$ 7.2	60.9 $\pm$ 7.4	<0.001	56.4 $\pm$ 7.6	57.8 $\pm$ 7.3	0.264
MAP (mmHg)	69.8 $\pm$ 7.5	78.4 $\pm$ 7.1	<0.001	72.6 $\pm$ 8.1	74.1 $\pm$ 7.8	0.287
paired t-test						

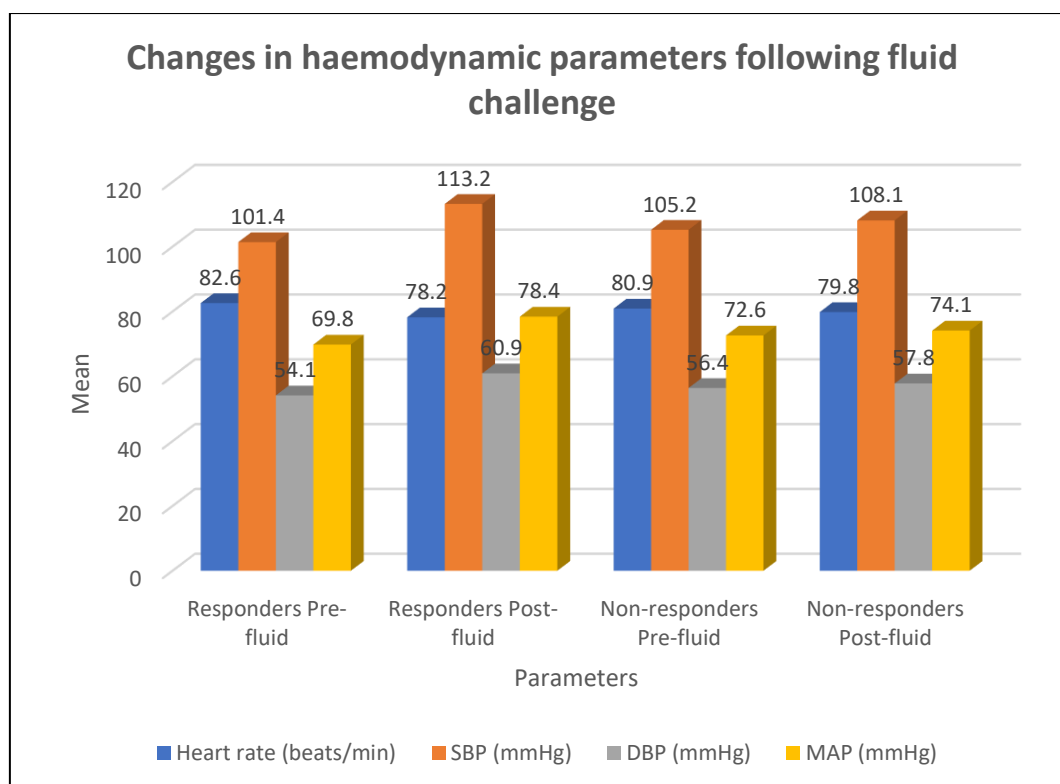


Figure 1. Changes in haemodynamic parameters following fluid challenge

Table 3. Comparison of POCUS parameters between responders and non-responders

POCUS parameter	Responders (n=52)	Non-responders (n=38)	p-value	Statistical test
Baseline maximum IVC diameter (cm)	1.63 ± 0.28	1.82 ± 0.30	0.003	Independent t-test
Baseline minimum IVC diameter (cm)	1.28 ± 0.25	1.58 ± 0.27	<0.001	
IVC respiratory variation (%)	21.8 ± 6.4	13.2 ± 5.1	<0.001	
Baseline LVOT-VTI (cm)	15.2 ± 2.6	18.1 ± 2.9	<0.001	
Post-fluid LVOT-VTI (cm)	18.4 ± 2.8	18.8 ± 2.9	0.511	
Change in LVOT-VTI (%)	21.4 ± 7.6	4.3 ± 3.1	<0.001	

Table 4. Pre- and post-fluid changes in POCUS parameters

Parameter	Pre-fluid	Post-fluid	Mean change	p-value	Statistical test
IVC maximum diameter (cm)	1.71 ± 0.30	1.86 ± 0.29	+0.15	<0.001	Paired t-test
IVC minimum diameter (cm)	1.41 ± 0.30	1.62 ± 0.28	+0.21	<0.001	
IVC respiratory variation (%)	18.2 ± 7.1	12.7 ± 5.4	-5.5	<0.001	
LVOT-VTI (cm)	16.4 ± 3.0	18.6 ± 2.8	+2.2	<0.001	

Table 5. Diagnostic performance of POCUS parameters for predicting fluid responsiveness

POCUS parameter	Optimal cut-off	AUC (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
IVC respiratory variation	>18%	0.84 (0.75–0.92)	82.7	78.9	84.3	76.9	81.1

Baseline LVOT-VTI	≤16.5 cm	0.79 (0.69–0.88)	76.9	73.7	80.0	70.0	75.6
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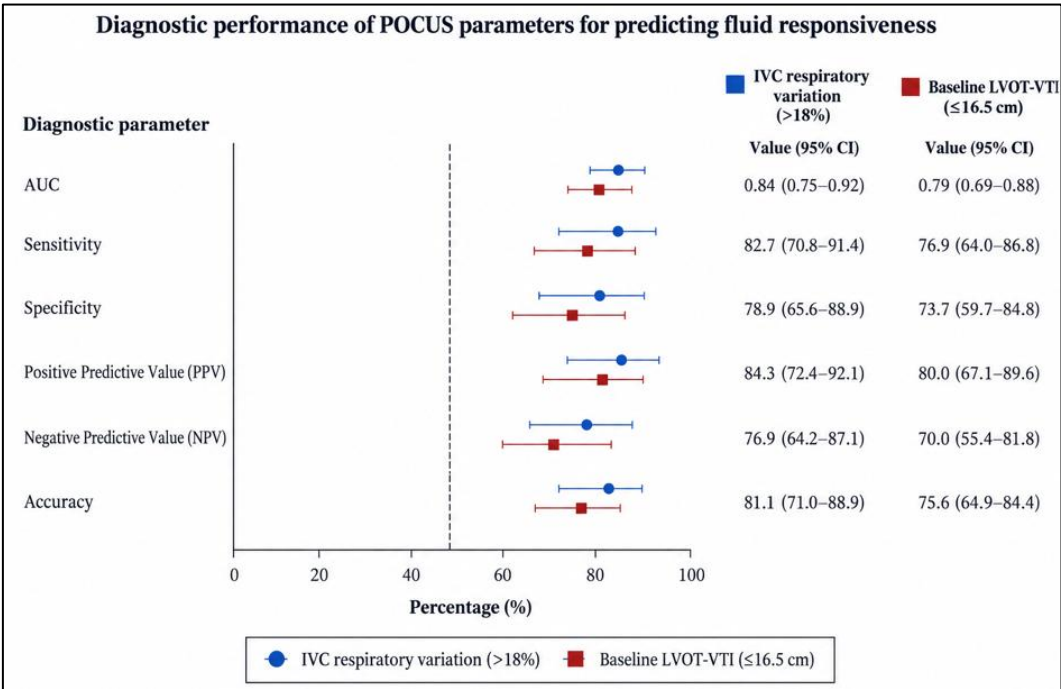


Figure 2. Diagnostic performance of POCUS parameters for predicting fluid responsiveness

Table 6. Correlation of POCUS and clinical variables with percentage change in stroke volume following fluid challenge

Variable	Correlation coefficient (r/p)	p-value	Statistical test
Age	−0.18	0.091	Pearson correlation
BMI	−0.14	0.189	
Baseline MAP	−0.21	0.047	
IVC respiratory variation (%)	0.58	<0.001	
Baseline LVOT-VTI (cm)	−0.46	<0.001	
Change in LVOT-VTI (%)	0.71	<0.001	

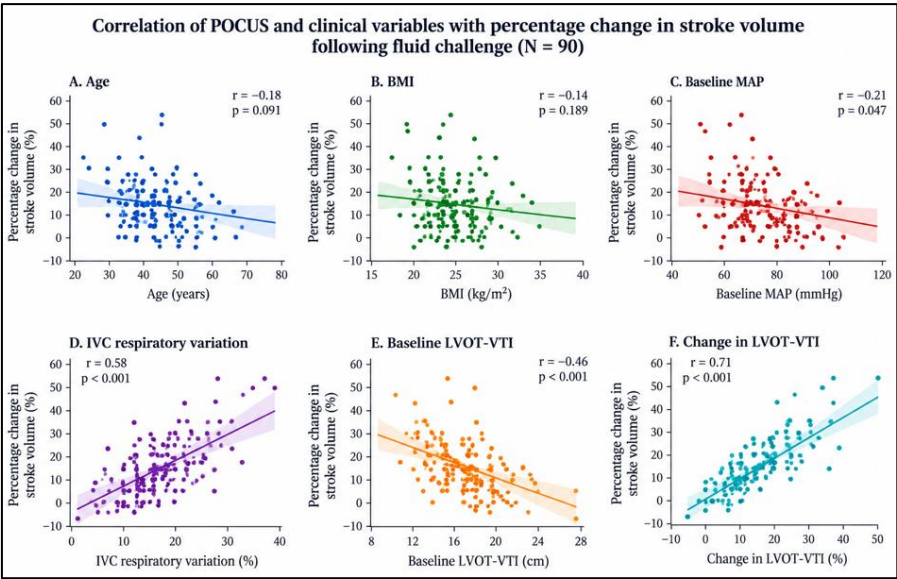


Figure 3. Correlation of POCUS and clinical variables with percentage change in stroke volume following fluid challenge

DISCUSSION

In the present study, 52 of 90 patients (57.8%) were fluid responders, while 38 (42.2%) were non-responders. In responders, MAP increased significantly from 69.8 ± 7.5 to 78.4 ± 7.1 mmHg ($p < 0.001$), compared with a smaller change from 72.6 ± 8.1 to 74.1 ± 7.8 mmHg among non-responders. Messina et al. [14] in the MANEUVER study similarly found that approximately half of surgical patients were fluid responsive, supporting the concept that volume expansion does not uniformly improve haemodynamics. Monnet et al. [15] also emphasised that volume expansion does not consistently increase cardiac output and recommended assessment of preload responsiveness before fluid administration.

Responders had significantly greater baseline IVC respiratory variation than non-responders ($21.8 \pm 6.4\%$ vs $13.2 \pm 5.1\%$, $p < 0.001$) and lower baseline LVOT-VTI (15.2 ± 2.6 vs 18.1 ± 2.9 cm, $p < 0.001$). Following fluid administration, the percentage increase in LVOT-VTI was also markedly greater in responders ($21.4 \pm 7.6\%$ vs $4.3 \pm 3.1\%$, $p < 0.001$). These findings support the physiological principle described by Monnet et al. [15] that dynamic changes in venous return and cardiac output are more informative for predicting fluid responsiveness than static preload measurements. They also noted that vena caval diameter variation can predict preload responsiveness, although its reliability depends on ventilation and other physiological conditions.

IVC respiratory variation showed good predictive performance in our study, with an AUC of 0.84 (95% CI 0.75–0.92). A cut-off of $>18\%$ provided 82.7% sensitivity, 78.9% specificity, and 81.1% diagnostic accuracy. Baseline LVOT-VTI ≤ 16.5 cm demonstrated an AUC of 0.79 (95% CI 0.69–0.88), sensitivity of 76.9%, and specificity of 73.7%.

Messina et al. [14] reported even higher discrimination for the mini-fluid challenge in the MANEUVER study, demonstrating that dynamic changes in stroke volume can effectively identify fluid-responsive surgical patients. However, Enevoldsen et al. [16] cautioned that the diagnostic performance of mini-fluid challenge studies may be overestimated. In their reanalysis, the mini-fluid challenge predicted the total fluid response with an AUROC of 0.92 but predicted response to the remaining 400 mL poorly (AUROC 0.33); a null simulation still produced an apparent AUROC of 0.73. These observations emphasise the need

for careful interpretation of diagnostic accuracy estimates.

IVC respiratory variation showed a significant positive correlation with percentage change in stroke volume ($r = 0.58$, $p < 0.001$), while baseline LVOT-VTI showed an inverse correlation ($r = -0.46$, $p < 0.001$). Change in LVOT-VTI demonstrated the strongest correlation with stroke volume response ($r = 0.71$, $p < 0.001$). These findings further support the use of dynamic POCUS parameters for assessing preload responsiveness, consistent with the physiological approach advocated by Monnet et al. [15]

Although IVC variation and LVOT-VTI demonstrated good diagnostic performance, their cut-offs should not be interpreted as absolute thresholds. Ray et al. [17] highlighted that biomarker evaluation should consider AUC, sensitivity, specificity, predictive values, and uncertainty surrounding diagnostic thresholds rather than relying on a single cut-off. Cannesson et al. [18] similarly demonstrated a "gray zone" for pulse pressure variation between 9% and 13%, within which fluid responsiveness could not be confidently classified; approximately 24% of patients fell within this range. Thus, POCUS measurements close to the identified cut-offs should be interpreted in conjunction with the overall clinical and haemodynamic condition.

CONCLUSION

POCUS-derived IVC respiratory variation and LVOT-VTI demonstrated good ability to predict fluid responsiveness in patients undergoing major surgery. Responders showed greater IVC variation and a greater increase in LVOT-VTI following fluid administration. POCUS may therefore provide a practical, non-invasive approach for individualising perioperative fluid therapy.

Limitations

The study was limited by its relatively small sample size and single-centre design. POCUS measurements are operator-dependent, and the findings may not be generalisable to patients with different ventilatory or haemodynamic conditions.

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