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Original Article

The Sonographic Measurement of the Inferior Vena Cava Diameter versus the Central Venous Pressure in Assessing Fluid Responsiveness in Patients after Coronary Artery Bypass Graft Surgery

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Abstract

Background: Fluid status assessment and management post coronary artery bypass grafting (CABG) is a clinical challenge. The study aimed to establish whether central venous pressure (CVP) and ultrasound measures of respiratory variability of inferior vena cava (IVC) diameter might predict fluid responsiveness in mechanically ventilated patients after CABG.

Methods: This comparative study included 200 consecutive adult patients who underwent elective CABG. We recorded the following parameters: heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), central venous pressure (CVP), inferior vena cava maximum (IVCmax), and minimum (IVCmin) diameters, left ventricular ejection fraction (LVEF), and velocity-time integral in the left ventricular outflow tract (VTI-LVOT).

Results: The age of the patients ranged from 45 to 71 years, and 147 were males (73.5%). Patients were grouped into fluid responders (n= 135), defined as stroke volume variation (SVV) of 15% or greater following fluid bolus administration, and fluid non-responders (n= 65), defined SVV of less than 15% following fluid bolus administration. There was no statistically significant difference between the groups regarding their CVP, maximum and minimum IVC diameters, inferior vena cava distensibility index (IVC-DI), and other markers of fluid responsiveness (p-value 0.47, 0.34, 0.59, and 0.64, respectively). There was a significant difference in SVV between fluid responders (18.33±2.767) and non-responders (10.95±1.940) (p-value <0.001).

Conclusion: Neither CVP nor sonographic measures of IVC diameter respiratory variability provided an accurate method to distinguish between fluid responders and non-responders in the early postoperative period after CABG.

KEYWORDS
Sonographic; Inferior Vena Cava; Central Venous Pressure; Fluid Responsiveness; Coronary Artery Bypass Grafting

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Introduction

Fluid management is critical for cardiothoracic surgery patients to optimize their hemodynamics [1]. Numerous studies have ascertained a relationship between volume overload and an increased fatality post-cardiac surgery [2]. Moreover, cardiothoracic surgery patients have limited myocardial reserve; therefore, fluids should be supplied with caution to those patients [3].

Preliminary evaluation of fluid responsiveness is critical before administering fluids, and

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numerous indicators have been used in clinical practice [4]. Central venous pressure (CVP) is a static measure of preload and does not anticipate fluid responsiveness, although traditional fluid management after cardiothoracic surgery relies on it [5]. Central venous access is necessary to measure CVP; however, it has complications such as arrhythmias, cardiac chamber damage, vascular-nerve injury, and pneumothorax [6]. According to current clinical studies, the sonographic measurement of respiratory variations of inferior vena cava (IVC) diameter seems to meet the criteria of an ideal bedside tool to assess fluid responsiveness [7]. Although this method has been tested in limited conditions (e.g., hemodialysis, septic shock, and subarachnoid hemorrhage), it is still unsettled in cardiac surgery [8].

The study aimed to determine whether central venous pressure measurements and ultrasound measurements of the respiratory variability of inferior vena cava (IVC) diameter were valid predictors of fluid responsiveness in mechanically ventilated patients after coronary artery bypass graft surgery (CABG).

Patients and Methods

Design and patients:

We conducted a study on 200 consecutive adult patients who were sedated and mechanically ventilated after elective CABG from January 2020 to January 2022. The local Ethical Committee approved the study. We obtained informed consent from all patients before commencing this study. Exclusion criteria were age <18 years, non-sinus rhythm, left ventricular ejection fraction (LVEF) less than 30%, left ventricular dilatation (end-diastolic diameter more than 6 cm), tricuspid valve regurgitation with severe symptoms that necessitated surgery, marked impairment in the right ventricle function (tricuspid annular plane systolic excursion <16 mm), the subjective difficulty of ultra-sound image acquisition because of a poor acoustic window, patients with spontaneous breathing activity, and morbidly obese patients.

Data:

The following parameters were recorded: heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), central venous pressure (CVP), maximal (dIVC max), minimal (dIVC min) diameters of inferior vena cava, inferior vena cava distensibility index (IVC-DI), LVEF, and velocity-time integral in the left ventricular outflow tract (VTI LVOT).

Techniques:

All patients had their central venous catheters inserted aseptically in the internal jugular vein, and a chest x-ray confirmed their correct position. A critical care physician and a licensed practical nurse took the CVP readings for the study. A transducer is used to assess central venous pressure at the location where the fourth intercostal space and the midaxillary line meet. After zeroing, the transducer was kept open for a while so that blood could flow into the central venous catheter. The waveform of central venous pressure and the average central venous pressure in mmHg were displayed on the monitor.

Figure 1: Measurement of inferior vena cave diameter using M- mode

The diameter of the IVC was measured using an ultrasound machine with a curvilinear ultrasound probe (3.5–5 MHz) and in the supine position. Inferior vena cava was visualized longitudinally in the subcostal view. Maximal and minimal diameters of IVC (dIVC max and dIVC min, respectively) were measured in M-mode, distally to the hepatic vein, over the respiratory cycle. Three measurements were attained and averaged for each IVC diameter (Figure 1). This formula was used to calculate IVC distensibility index (IVC-DI): IVC-DI = dIVC max - dIVC min / dIVC min that was expressed as a percentage.

The stroke volume variation (SVV) technique is the gold standard for fluid responsiveness. Calculating stroke volume (SV) from the LVOT was performed according to the following equation: SV = 0.785 x dLVOT2 x VTI LVOT. When the patient was supine in a parasternal long-axis view, close to the aortic valve in the middle of the systole, the left ventricular outflow tract diameter (dLVOT) was measured. Using a five-chamber apical picture of the heart and pulsed Doppler imaging, we were able to measure the LVOT velocity time integral (LVOT VTI). When it came to measuring the left ventricular ejection fraction (LVEF), visual inspection was used.

Fluid challenge test:

Internal volume expansion was achieved by administering 250 milliliters of isotonic saline solution intravenously over 10-15 minutes or at the speediest rate available at the time of administration. A 15% or greater increase in stroke volume after the fluid challenge was considered to be a sign of fluid responsiveness. Responders and non-responders were split into two categories by this method (Figure 2).

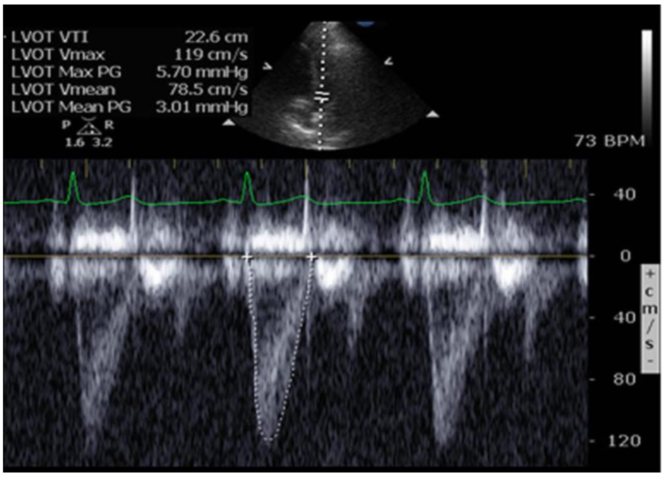

Figure 2: Measurement of velocity-time integral tracing by pulse wave Doppler in the left ventricular outflow tract

Statistical analysis:

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 26.0 (SPSS Inc., Chicago, Illinois, USA). Qualitative information was depicted using mean and standard deviation values (SD). The frequency and percentage distributions were used to depict the qualitative data. The inquiry included the following procedures: Independent-samples t-test was performed to determine whether or not the difference between two mean values was statistically significant. The relevance of qualitative characteristics was assessed by comparing their proportions using the chi-square (χ2) test. A p-value of less than 0.05 was considered statistically significant.

Results

The age of the patients ranged from 45 to 71 years. Among 200 studied patients, 147 patients were male (73.5%), and 53 patients were female (26.5%). Patients were classified into fluid responders and non-responders based on a ≥15 % increase in stroke volume after receiving 250 ml of IV isotonic saline solution. Responders were 135 patients (67.5%) while non-responders were 65 patients (32.5%).

Table 1: Comparison of demographic data between fluid responders and non-responders. Continuous data were presented as mean and standard deviation, and categorical data as numbers and percentages.

	Fluid Responder (n= 135)	**Fluid Non-responder (n= 65)**	***p*-value**
Age (years)	57.12±5.785	57.18±6.172	0.94
Gender (M:F)	100:35 (74.07%:25.92%)	47:18 (72.3%:27.69%)	0.79
BMI (kg/m^2)	28.453±2.9381	27.703±2.6039	0.08

BMI: Body Mass index; F: Female; M: Male

There was no statistically significant difference between patients regarding age, gender, or body mass index (Table 1). The hemodynamic measures, including heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial blood pressure, did not significantly differ between the two groups (MAP) (Table 2).

The central venous pressure, diameters of the inferior cava, and the inferior vena cava distensibility index did not differ significantly between the fluid responders and the non-responders. There was a statistically significant difference between fluid responders and non-responders regarding stroke volume variation. (Table 3).

Table 2: Comparison of hemodynamic parameters between fluid responders and non-responders. Continuous data were presented as mean and standard deviation.

	Fluid Responder (n= 135)	Fluid Non-responder (n= 65)	*p*-value
HR (bpm)	81.04±7.142	82.77±8.669	0.138
SBP (mmHg)	114.77±13.213	113.06±15.062	0.414
DBP (mmHg)	63.03±8.825	62.09±8.499	0.477
MAP (mmHg)	80.15±9.611	78.85±10.288	0.382

HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial blood pressure

Table 3: Comparison of the ultrasound inferior vena cava-derived parameters and central venous pressure between fluid responders and non-responders. Continuous data were presented as mean and standard deviation

	Fluid Responder (n= 135)	Fluid Non-responder (n= 65)	*p*-value
CVP (mmHg)	9.48±2.967	9.80±2.846	0.472
dIVC min (mm)	1.38±0.18	1.39±0.197	0.599
dIVC max (mm)	1.99±0.241	2.023±0.2	0.340
IVC-DI (%)	45.04±18.75	46.34±17.77	0.641
SVV (%)	18.33±2.767	10.95±1.940	< 0.001

CVP: central venous pressure; dIVC min: minimal diameter of inferior vena cava; dIVC max: maximal diameter of inferior vena cava; IVC-DI: inferior vena cava distensibility index, SVV: stroke volume variation

Discussion

CABG patients are often given large amounts of intravenous (IV) fluids, which might be potentially harmful. Because of the increased capillary permeability and hemodilution that occur during an on-pump cardiac surgery, the already tough situation is made much more severe. Consequently, diagnostic methods that can identify between those patients who would benefit from preload augmentation and those who would not benefit are crucial for hemodynamic optimization of these patients.

There was no statistically significant difference in the population's initial baseline hemodynamic data (heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure). As a result, these tests could not evaluate the research population's fluid responsiveness.

This result is consistent with Qi and colleagues [9]. They performed a retrospective study including 68 patients receiving fluid therapy in ICU to assess the fluctuations in HR, MAP, SBP, DBP, pulse pressure before and after fluid administration. They did not report differences between responders and non-responders.

Patients in critical condition should be monitored by their central venous pressure (CVP), which is the most crucial metric to use while administering fluids. As a predictor of fluid responsiveness, several studies have demonstrated that alternative markers are better than the CVP in various instances. Aside from the left ventricle's function and preload, the right ventricle's function and preload may be determined using CVP. Consequently, CVP measurements may be useful in directing fluid management in some circumstances. It is possible to misinterpret CVP measures due to chest, pericardium, and abdomen pressures. Although the CVP obtained in these circumstances is more significant than the transmural CVP and hence may not accurately represent the true loading conditions of the right ventricle, it reveals the venous return limit and backpressure of all extrathoracic organs. There is an increased risk of peripheral edema, ascites, kidney and liver injury, and an elevated absolute CVP score. According to their central venous pressure, there was no statistically significant difference between fluid responders and fluid non-responders. In compliance with that, Osman and colleagues [10] performed a study including 150 fluid challenges performed in 96 mechanically ventilated patients and found that there was no difference between fluid responders and non-responders in terms of their baseline CVP, indicating that CVP had a low predictive value. Also, Eskesen and coworkers [11] executed a comprehensive assessment of 1148 individuals from 51 studies testing the reaction to a fluid bolus, and the researchers determined that CVP had a poor predictive value.

Furthermore, Marik and associates [5] performed a meta-analysis that included 43 studies examining fluid responsiveness features. Additionally, they studied the correlation coefficients and/or area under the curve between central venous pressure changes in stroke volume indexes/cardiac index and the percentage of fluid responders and their baseline central venous pressure. A lack of correlation between the CVP and RA pressure and the cardiac index, as well as a lack of correlation between CVP changes and changes in stroke volume as a result of volume loading, were the reasons given for the lack of correlation between CVP and fluid responsiveness, according to their findings. CVP may be useful in such scenarios if there are no alternative procedures for testing fluid responsiveness through dynamic variables.

CVP remains the gold standard for post-cardiothoracic surgery fluid management despite advances in technology. According to generally recognized professional guidelines, a CVP of 8-12 mmHg remains the objective criterion for postoperative fluid delivery. According to our data, CVP is not a reliable predictor of fluid responsiveness after CABG surgery. This was consistent with Sobczyk and coworkers [12], who assumed that CVP was shown to be a poor predictor of fluid responsiveness; nonetheless, it was found to be higher in fluid responders than non-responders (P=0.35).

The inferior vena cava diameter may be measured using ultrasonography, which is non-invasive and can be done right at the patient's bedside. The value of this method has been endorsed in patients on hemodialysis and those with septic shock. Because of their ease of use, repeatability, and diagnostic value, the dynamic IVC diameter respiratory variability metrics (collapsibility index and distensibility index) have grown more popular as a diagnostic means of fluid responsiveness. This is consistent with Barbier and colleagues [8], who studied 23 mechanically ventilated patients with severe circulatory failure and revealed that IVC-DI might accurately predict fluid responsiveness in septic shock. Correspondingly, Moretti and coworkers [13] included 31 patients who had had a subarachnoid hemorrhage in a study examining the reliability of the IVC-DI.

In the same way, Machare-Delgado and associates [14] used the Vigileo monitor to collect data on IVC respiratory variability and stroke volume variation in 25 mechanically ventilated patients (acute respiratory distress syndrome, cardiac arrest, sepsis). SVV measurement is difficult, time-consuming, and inaccurate for sepsis patients, while sonographic IVC respiratory variability may be rapidly obtained and effectively predicts fluid responsiveness. Ferrada and colleagues [15] used limited transthoracic echocardiography to quickly and non-invasively monitor fluid status in non-ventilated and ventilated patients, independent of ventilator settings. Long et and colleagues [16] analyzed more than 500 patients in a systematic analysis of 17 studies. They found that IVC variability in mechanically ventilated patients is a better predictor of fluid responsiveness. According to Huang and coworkers [17], IVC-DI had an AUC of 0.82 (95 percent confidence interval: 0.79–0.85), a specificity of 80%, and a sensitivity of 69% in mechanically ventilated shocked individuals. The IVC-DI has been proven to be a valid predictor of fluid responsiveness in critically ill patients who are mechanically ventilated, with a cut-off value of 18%, differentiating responders from non-responders in the research group.

Ultrasonographic monitoring of IVC variability with breathing could not attain statistical significance when comparing the two groups. This finding is consistent with Charbonneau and colleagues [18], who reported that the IVC-DI data from 44 medical and surgical septic mechanically ventilated patients had an AUC of 0.43 and a 95% confidence interval of 0.25–0.61, with 38% sensitivity and 61% specificity. Additionally, Si and colleagues [19] studied 753 patients who were ventilated with a tidal volume (TV) of 8 mL/kg or more and positive end-expiratory pressure (PEEP) of 5 cmH2O or less in 12 trials. Thus, they observed that in patients with a TV of less than 8 mL/kg or PEEP more than five cmH2O, the respiratory variability of the IVC diameter had little capacity to assess fluid responsiveness. Patients with these diseases should utilize IVC-derived measures with caution.

Relatedly, Sobczyk and colleagues [12] incorporated thirty-five individuals in a prospective case series study with an LVEF of 30% or above who were considered for elective CABG. They performed transthoracic echocardiography, passive leg lifts, intravenous saline infusions, and ultrasonographic measurements of the IVC diameter variability measures (CI and DI). Their results found that neither maximal diameter of the IVC nor dynamic variables produced by IVC were effective predictors of fluid responsiveness. According to the researchers, passive leg raising was also equally effective as volume expansion in distinguishing fluid responders from non-responders in the fluid response test.

We only measured IVC diameters and distensibility indexes in the supine position as a precautionary step. This was consistent with prior results by Mookadam and associates [20], who disclosed that supine patients compared to patients in lateral position had an IVC width of 17.2+4.1 mm versus 10.9+4.4mm and 16.2+4.5mm versus 9.9+4.4mm, respectively (p< 0.001 in both cases).

In this study, the group of fluid non-responders had a mean SVV of 10.95 ± 1.94%, whereas fluid responders had a mean SVV of 18.33 ± 2.76%. These data pointed out that fluid responders had a considerably greater SVV than non-responders (p<0.001). This matches with the previous studies such as Kaur KB and colleagues, [21] who stated that fluid responsiveness was correlated with SVV/dIVC. According to the findings, Sixty-seven percent of the participants in the study reacted to the volume challenge. There was a statistically significant positive correlation (r = 0.474) between the two factors when fluid non-responders were examined at baseline. The Bland-Altman dIVC-SVV correlation showed a mean difference of 4.4 after the fluid challenge. The Pearson's correlation graph showed a strong positive connection between dIVC and SVV (p-value = 0.047). Above and beyond, De Waal and colleagues [22] investigated 22 elective coronary artery bypass graft patients in closed and open chest settings using dynamic metrics such as pulse pressure variation (PPV) and stroke volume variation (SVV). In closed-chest settings, fluid responsiveness could be anticipated by the dynamic preload indicators PPV and SVV. Still, fluid response prediction was problematic by all static and dynamic preload markers in open-chest procedures.

Study limitations and prospects

Because the present study was performed on adult patients who underwent coronary artery bypass graft surgery, the patient population analyzed was restricted. Hence, this tool cannot be generalized to other cardiac surgery situations. Additionally, IVC-derived indices were only useful in mechanically-ventilated patients and were inconsistent in patients with spontaneous breathing or on partial ventilatory assistance. The IVC evaluation may be inaccurate in individuals with intra-abdominal hypertension. Additionally, IVC assessment is operator-dependent, and one must get comfortable with the technique of doing an ultrasound scan before using IVC diameter in daily practice. Finally, this study was constrained by the small sample size, which may have reduced the study's power and increased the margin of error.

Conclusion

Neither CVP nor sonographic measures of IVC diameter respiratory variability provided an accurate method to distinguish between fluid responders and non-responders in the early postoperative period after CABG.

Conflict of interest: Authors declare no conflict of interest.

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