Bedside Ultrasonographic Measurement of the Inferior Vena Cava Fails to Predict Fluid Responsiveness in the First 6 Hours After Cardiac Surgery: A Prospective Case Series Observational Study

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Objective: To assess validity of respiratory variation of inferior vena cava (IVC) diameter to predict fluid responsiveness and guide fluid therapy in mechanically ventilated patients during the first 6 hours after elective cardiac surgery.

Design: Prospective observational case series study.

Setting: Single-center hospital.

Patients: 50 consecutive patients undergoing elective cardiac surgery.

Interventions: Transthoracic bedside echocardiography.

Measurements and Main Results: Parameters derived from ultrasonographic assessment of the IVC diameter (collapsibility index [CI], distensibility index [DI], and IVC/aorta index). In the whole study group, change in fluid balance correlated with change in IVC maximum diameter ($p = 0.034$, $r = 0.176$). IVC-CI and IVC-DI correlated with IVC/aorta index. A weak correlation between central venous pressure (CVP) and IVC-derived parameters (IVC-CI and IVC-DI) was noticed. Despite statistical significance ($p < 0.05$), all observed correlations expressed low statistical power ($r < 0.21$). There were no statistically significant differences between fluid responders and nonresponders in relation to clinical parameters, CVP, ultrasound IVC measurement, and IVC-derived indices.

Conclusion: Dynamic IVC-derived parameters (IVC-CI, IVC-DI, and IVC/aorta index) and CVP are not reliable predictors of fluid responsiveness in the first 6 hours after cardiac surgery. Complexity of physiologic factors modulating cardiac performance in this group may be responsible for the difficulty in finding a plausible monitoring tool for fluid guidance. Bedside ultrasonographic measurement of IVC is unable to predict fluid responsiveness in the first 6 hours after cardiac surgery.

KEY WORDS: ultrasound-guided fluid therapy, cardiac surgery, inferior vena cava, fluid responsiveness

ADEQUATE VOLUME THERAPY is one of the most important issues in the postoperative intensive care management after cardiothoracic surgery. Accumulating data suggest that underperfusion leads to inadequate organ perfusion, whereas overzealous perfusion is related to postoperative complications, increased hospital stay, and mortality.[1–6] Hence, the goal of the volume therapy is to supplement cardiac filling volume only as long as it improves stroke volume. The term "fluid responsiveness" describes this relation and justifies fluid challenge if it stays on the volume-dependent steep portion of the Frank-Starling curve.[7]

Numerous monitoring measures have been tested to navigate fluid therapy, but the data about their usefulness are still conflicting.[8] Central venous pressure traditionally has been used to guide fluid therapy after cardiothoracic surgery in Europe, although it is well documented that this static measure of preload does not predict fluid responsiveness.[9] Ultrasonographic measurement of the inferior vena cava (IVC) diameter with respiratory variation (collapsibility index [CI] and distensibility index [DI]) is quick, simple, and easy to learn. It seems to meet the criteria of an ideal bedside tool for fluid status assessment.[10,11] This method, however, has been validated in selected populations only (eg, hemodialysis, septic shock, and mechanical ventilation),[12–16] and its usefulness has not been confirmed in patients after cardiac surgery.

The purpose of this study was to assess the usefulness of dynamic parameters derived from IVC diameter (collapsibility index, distensibility index, and IVC/aorta index) as a guiding tool for fluid therapy in mechanically ventilated patients during the first 6 hours after elective cardiac surgery.

METHODS AND STUDY POPULATION

This observational study was approved by the local ethical committee (reference number 792/20014), and informed consent was obtained from all study participants.

The study population consisted of 50 consecutive adult patients admitted to the authors' hospital for elective cardiac surgery. Exclusion criteria were age <18 years, preoperative severe tricuspid valve regurgitation, preoperative right ventricular dysfunction (tricuspid annular plane systolic excursion <16 mm), and difficult acoustic window, resulting in inability to obtain interpretable ultrasound images. Total intravenous anesthesia with propofol, sufentanil, and pancuronium was used during the procedure. All the patients had surgery with moderate hypothermia (32°C-33°C) and warmed up to 36.6°C within 2 hours after the end of the operation. Propofol infusion was continued for 1 hour in the intensive care unit (ICU), and morphine infusion was used for postoperative pain relief. Cardiac ultrasound was performed when patients were still ventilated (synchronited intermittent mandatory ventilation-mode, tidal volume: 8 mL/kg, positive end-expiratory pressure: 4.5 cmH_2O).

The following baseline data were recorded for each patient: Age (years), weight (kg), height (cm), diagnosis, type of cardiac surgery and preoperative echocardiographic parameters (left ventricular ejection fraction, presence of left ventricular hypertrophy, right ventricular end-diastolic diameter, and tricuspid regurgitation grade).

Transthoracic bedside echocardiography was performed by 2 trained investigators, both with at least 5 years of experience in emergency ultrasound. The examinations were conducted with a

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1053-0770/2601-0001$36.00/0

http://dx.doi.org/10.1053/j.jvca.2014.08.015

portable ultrasound system equipped with a 1-5 MHz transthoracic phased-array transducer (CX 50 Philips, Eindhoven, The Netherlands). All cases were recorded as digital clips and reviewed independently by all authors.

The inferior vena cava was visualized longitudinally in the subcostal view (Fig 1). Maximal and minimal IVC diameters (IVCmax and IVCmin, respectively) were measured using a two-dimensional image, 2 cm proximally from the hepatic vein inlet, over a single respiratory cycle. The maximal aortic diameter was obtained from the subcostal view 0.5 to 1 cm above the celiac trunk (Fig 2). A total of 3 measurements were obtained and averaged for each IVC and aortic diameter. The IVC collapsibility index (IVC-CI), a measure of the relative decrease in diameter during 1 respiratory cycle, was defined as IVC-CI = IVCmax – IVCmin/IVCmax. The IVC distensibility index (IVC-DI), which reflects an increase in its diameter during inspiration, was calculated using the formula IVC-DI = IVCmax – IVCmin/IVCmin. Both indices were expressed as a percentage. The IVC/aorta index was defined as IVCmax/aortic diameter.

The left ventricular outflow tract diameter (dLVOT) was measured in midsystole, in a parasternal long-axis view immediately adjacent to the aortic valve. LVOT velocity time integral (LVOT VTI) was recorded by pulsed Doppler imaging from a three-chamber or five-chamber apical view. Cardiac output (CO) was calculated from the left ventricular outflow tract (LVOT), using the previously described equation:[17] $CO = 0.785 \times dLVOT^2 \times VTI\ LVOT \times$ heart rate (HR). Left ventricular ejection fraction (LVEF) was assessed by visual inspection.

Clinical data and ultrasound measurements were recorded at 4 defined points per enrollment: Baseline (just after the cardiac procedure when the patient was transferred to the intensive care unit) and at 2-hour intervals over 6 hours after the surgery (2 hours, 4 hours, and 6 hours). The following parameters were obtained at each time point: HR (bpm), systolic blood pressure (mmHg), diastolic blood pressure (mmHg), central venous pressure (CVP, mmHg), fluid balance, vasoactive agents dosage, IVCmax (mm), IVCmin (mm), aortic diameter (mm), LVEF (%), and VTI LVOT (mm). The following values were considered cut-off points for intermediate doses of catecholamine infusion: 3 μg/kg/min of dopamine, 5 μg/kg/min of dobutamine, 4 μg/min of epinephrine, and 3 μg/min of norepinephrine.[18] Fluid responsiveness was defined as an increase in cardiac output ≥15% after the fluid challenge, which defined patients as responders and nonresponders. Any clinically significant findings (eg, severe left ventricular dysfunction and cardiac tamponade) were reported immediately to the treating physician.

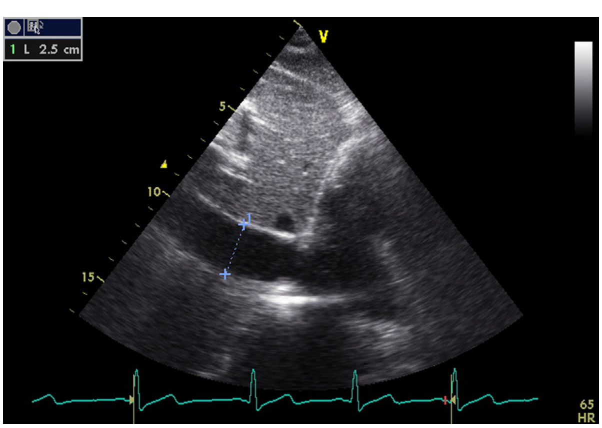

Fig 1. Subcostal view: measurement of inferior vena cava maximal diameter.

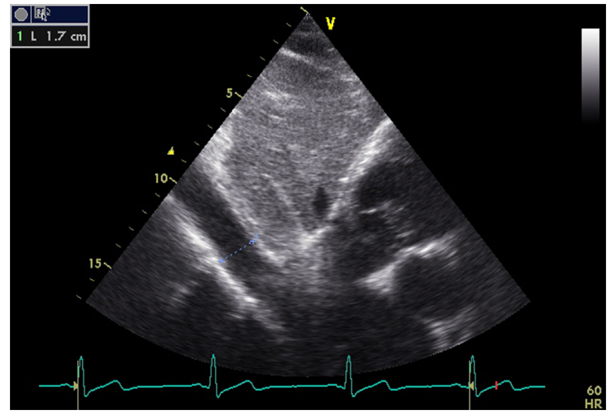

Fig 2. Subcostal view: Measurement of aortic diameter.

Statistical analysis was performed using STATISTICA version 8.0 software (Dell Inc., Round Rock, TX). Numerical data were expressed as mean values ± SD. After checking the homogeneity of variance, the comparisons between fluid responders and nonresponders were performed with the Student's *t* test for independent variables. A p value of 0.05 was considered significant. Given a normal probability distribution, correlations between the clinical and IVC-derived parameters were evaluated with Pearson's correlation analysis (r value). Scatterplots for the 2 variables of the linear regression were drawn for IVC-CI, IVC-DI, and CVP, with confidence interval 0.95.

RESULTS

Fifty consecutive patients (33 male, aged 35-85 years, median 65 years, mode 63 years) were enrolled to the study. Baseline demographic and clinical data are shown in Table 1. All patients were in sinus rhythm. The mean volume of fluids administered intraoperatively was 2,902.8 ± 817.041 mL. The mean postoperative intravenous fluid intake within the first 6 hours was 2,625 ± 778 mL. All patients receiving at least moderate or increasing doses of catecholamines were excluded from the final statistical analysis. Patients were divided into fluid responders and nonresponders based on a ≥15% increase in cardiac output after the fluid challenge. Table 2 provides comparison between responders and nonresponders. There were no statistically significant differences between groups in relation to clinical parameters (HR, systolic blood pressure, LVEF), fluid balance, CVP, IVC diameter and IVC-derived indices. IVC-derived parameters (IVC-CI, IVC-DI, IVC/aorta index) were tested for correlation with CVP and fluid balance (Table 3). Change in fluid balance correlated with change in IVCmax ($p = 0.034$, $r = 0.176$). IVC collapsibility index and