Hemodynamic Pressure Waveform Analysis in Predicting Fluid Responsiveness

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Objective: **To assess the usefulness of central venous pressure (CVP), diastolic right ventricular pressure, and pulmonary capillary wedge pressure (PCWP) waveform analysis in predicting fluid responsiveness.**

Design: **A prospective observational study.**

Setting: **Tertiary care university hospital.**

Patients: **Forty-four patients undergoing coronary artery bypass grafting.**

Interventions: **Analysis of the a/v wave ratio of the PCWP, CVP, and right ventricular dP/dt to predict an increase in stroke volume >15% after the administration of 500 mL of colloid.**

Measurements and Main Results: **Forty-four patients were enrolled in this study and 7 were excluded. There were 24 responders and 13 nonresponders. No differences in mean CVP and PCWP values between the responders and the nonresponders were found. The only parameter associated with a significant response to volume infusion was the ratio of the a/v waves of the PCWP tracing ($p = 0.0001$). The performance of the a/v wave ratio >1 of the PCWP tracing in predicting fluid responsiveness was evaluated by constructing a receiver operating characteristic curve. The area under the receiver operating characteristic curve was 0.89 (95% confidence interval, 0.79-0.99; $p < 0.05$).**

Conclusions: **The a/v ratio measured on the PCWP tracing is a predictor of fluid responsiveness in patients with preserved left ventricular function undergoing coronary artery bypass grafting.**

KEY WORDS: *cardiac surgery; hemodynamic monitoring; preload responsiveness; pulmonary artery pressures; a/c waves*

PRELOAD OFTEN IS ESTIMATED clinically using central venous pressure (CVP), pulmonary capillary wedge pressure (PCWP),[1] or transesophageal echocardiography (TEE). TEE, as a direct measurement of left ventricular (LV) end-diastolic area, more accurately reflects LV preload than PCWP.[2] However, preload responsiveness, defined as an increase in cardiac output (CO) following volume administration, has emerged as a clinically relevant concept in the evaluation of preload. Fluid responsiveness, which is either present or absent, is determined by several factors, including the relative position on the diastolic-pressure volume relationship.[3-5] Thus, no single CVP, PCWP, or LV end-diastolic area threshold value can predict a positive response to fluid challenge.[6] Dynamic parameters such as respiratory variations in the inferior or superior vena cava diameters,[7-9] systolic pressure variation (SPV), and pulse pressure variation all have been shown to be superior to these static parameters in their ability to predict volume responsiveness.[10]

In patients monitored with CVP and pulmonary artery catheters (PACs), both CVP and PCWP pressure waveform analysis easily can be obtained. The a wave represents atrial contraction, and the v wave represents atrial filling before opening of the mitral or tricuspid valve. These waveforms are influenced by right ventricular (RV) and LV diastolic function. The slope of the diastolic portion of the RV tracing also can be measured.[11] The authors hypothesized that if the v wave was lower and smaller than the a wave and the slope of the diastolic RV pressure tracing was normal or slightly inclined, then the heart could accommodate further volume and increase CO. This state would correspond to either a normal diastolic pattern or impaired relaxation pattern using TEE. Conversely, if the v wave was higher than the a wave, and the slope of the diastolic RV pressure tracing was steep, the heart was already maximally filled and fluid responsiveness would be absent. Fig 1 summarizes the authors' hypotheses.

METHODS

After approval by the research and ethics committee and with informed consent, 44 patients undergoing elective coronary artery bypass grafting (CABG) surgery were included. Patients with significant valvular heart disease, intracardiac shunts, and preoperative arrhythmias were excluded from the study. Further exclusion criteria included contraindications to TEE, such as esophageal disease or an unstable cervical spine, and patients with an initial CVP or PCWP value ≥15 mmHg. Preoperative data included demographic information and the presence of comorbid conditions.

Patients were premedicated with 0.1 mg/kg of morphine and 0.03 to 0.1 mg/kg of midazolam administered intramuscularly before being taken to the operating room. Usual monitoring was used, including a 5-lead electrocardiogram, pulse oximeter, peripheral venous catheter, radial arterial catheter, 15-cm 3-lumen catheter (CS-12703, Arrow international Inc, Reading, CA), and fast-response thermodilution pulmonary artery catheter (Swan-Ganz catheter 7.5 Fr; Baxter, Irvine, CA). The pressure waveforms were measured with a disposable pressure transducer (Edwards Lifesciences, Irvine, CA) and 72-inch fluid-filled low-compliant tubing. Anesthesia was induced with 0.04 mg/kg of midazolam and 1 μg/kg of sufentanil, and muscle relaxation was achieved with 0.1 mg/kg of pancuronium. After tracheal intubation, anesthesia was maintained with 1 μg/kg/h of sufentanil and 0.04 mg/kg/h of midazolam and propofol at 30 to 50 μg/kg/min. Isoflurane was used as needed at the discretion of the attending anesthesiologist. The lungs were ventilated by intermittent positive-pressure ventilation with a fraction of inspired oxygen of 1.0 using an

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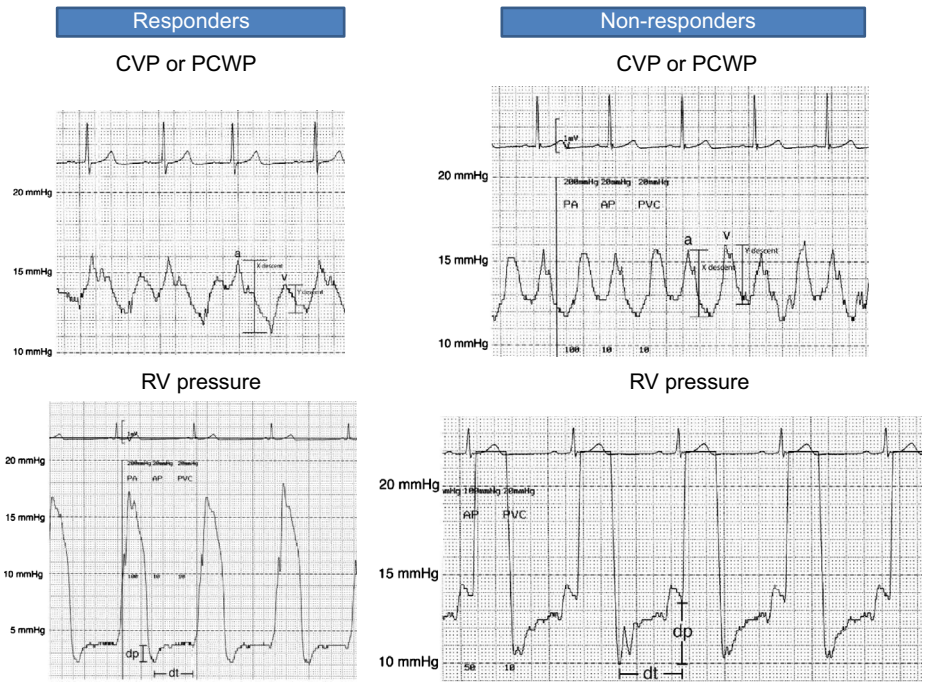

Fig 1. Hemodynamic waveform analysis in predicting fluid responsiveness; a, a wave of the CVP or PCWP waveform tracing; v, v wave of the CVP or PCWP waveform tracing. (Color version of figure is available online.)

Ohmeda volume-cycled ventilator (Datex-Ohmeda, Helsinki, Finland), with a respiratory rate of 8 breaths/min, a tidal volume of 8 mL/kg, and a inspiratory-to-expiratory ratio of 1:2. These parameters were kept constant for the entire experiment. Fluid and medications were administered as needed according to the patient's clinical status. A 5.0 MHz TEE omniplane probe (Hewlett Packard Sonos 5500, Andover, MA) was inserted after induction of general anesthesia.

After the induction of anesthesia, measured hemodynamic parameters included CVP, pulmonary artery pressure (PAP), and PCWP values. The pressure waves were recorded from a Siemens-Sirecust 1281 monitor (Siemens, Andover MA), with a scale of 20 mmHg, at a speed of 25 mm/s, and printed with a Hewlett Packard LaserJet 2300 L printer for further analysis of the a and v waves on 3 consecutive cardiac beats. All recordings were determined during a short period of apnea. All pressure measurements and recordings were performed by the same investigator. The RV pressure was measured via the paceport of the Swan-Ganz catheter as previously described.[12] The slope of the diastolic portion of the tracing was printed and dP/dt measured. CO was assessed by using the thermodilution technique with 3 injections of room-temperature dextrose 5% (10 mL) at end-expiration. These measurements were taken after anesthetic induction, before the opening of the chest during a period of hemodynamic stability, and both before and after a rapid-volume infusion of 500 mL of 10% pentastarch (Pentaspan; Dupont Pharma Inc, Mississauga, Ontario, Canada) given over 5 minutes with the chest closed. A baseline TEE examination was performed prior to volume infusion according to the guidelines of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists.[12,13] LV diastolic function was classified using published guidelines.[14] The authors' interobserver variability in the evaluation of diastolic function previously has been reported.[15,16] Fluid responsiveness was defined as an increase in stroke volume (SV) $>15\%$.[10]

Comparison of baseline hemodynamic parameters between responders and nonresponders was performed using t-tests. When a difference between responders and nonresponders was found, sensitivity, specificity, and positive predictive and negative values to predict an increase in SV $>15\%$ were calculated using standard formulae. Receiver operating characteristic (ROC) curves were generated to assess the ability of hemodynamic variables to discriminate between positive and negative response to fluid challenge. The area under the ROC curve and the related 95% confidence interval were calculated. The area under the ROC curve represented the probability that a random pair of responders and nonresponders after fluid infusion would be ranked correctly. A value of 0.5 indicates that the screening measure was no better than chance, whereas a value of 1 implied perfect performance. If the related 95% confidence interval of an area under the ROC curve did not include the value 0.5, this confirmed the ability of the hemodynamic variables under study to discriminate between positive and negative responses to a fluid challenge. The difference in the hemodynamic variables between baseline and the post-fluid infusion measurements was studied using paired t-tests on the overall sample. Descriptive statistics were expressed as mean $\pm$ standard deviation. A p value <0.05 was considered statistically significant. Statistical analyses were performed with SAS version 9.2.

RESULTS

Forty-four patients undergoing CABG were enrolled in this study. Seven patients were excluded from the analysis, for a total of 37 patients. The reasons for exclusion were initial CVP value ≥ 15 mmHg (n = 1), technical failure of the thermodilution catheter (n = 1), uninterpretable CVP and PCWP tracings due to artifacts (n = 3), and scheduling conflict (n = 2). There were 7 women and 30 men included in the study, with a mean age of 60.2 ± 9.6 years. Twenty-three patients had hypertension, 11 were diabetic, 1 had chronic obstructive pulmonary disease, and 6 had mild LV failure (LV ejection fraction between 40% and 50%). TEE evaluation of LV diastolic function was available in only 26 patients. Of the nonresponders, all 8 patients with TEE evaluation of diastolic