Precision of Echocardiographic Estimates of Right Atrial Pressure in Patients with Acute Decompensated Heart Failure

Rayji S. Tsutsui, MD, Allen Borowski, RDCS, W. H. Wilson Tang, MD, James D. Thomas, MD, and Zoran B. Popović, MD, PhD, *Cleveland, Ohio*

Background: Several methods that estimate right atrial pressure (RAP) from echocardiographic parameters have been proposed. However, their precision (i.e., how much they decrease RAP estimation uncertainty) is unknown. The aim of this prospective study was to evaluate and compare the precision of previously proposed RAP estimates in patients with acute decompensated heart failure.

Methods: Echocardiographic and invasive hemodynamic data were acquired in 75 patients with acute decompensated heart failure. Measurements were made at the start and 48 to 72 hours after the beginning of treatment. RAP was estimated by method 1, using the cutoffs defined by inferior vena cava diameter (IVCd) and IVCd percentage change (IVCd%change) during inspiration, and by method 2, using IVCd%change and systolic to diastolic hepatic flow ratio (S/D_{hep}). Method 3 was used in patients with sinus rhythm, using the ratio of early tricuspid inflow and early diastolic tissue Doppler tricuspid annular velocities (E/E'_{ta}). RAP was also estimated by resting IVCd, IVCd during inspiration, IVCd%change, right ventricular regional isovolumetric relaxation time, E/E'_{ta}, right atrial volume index, S/D_{hep}, right ventricular Tei index, right ventricular E/A, and right atrial emptying fraction. Precision gain was measured as the difference between the standard deviation of RAP and the standard error of the estimate of RAP.

Results: Method 1 ($r = 0.48$, $P < .05$), IVCd during inspiration ($r = 0.49$, $P < .0001$), IVCd%change ($r = 0.41$, $P < .0001$) and IVCd ($r = 0.40$, $P < .0001$) had the highest correlation with RAP. The highest gain in precision was also observed with the above methods (9%, 13%, 9%, and 8%, respectively). All other parameters had poor correlation with RAP.

Conclusion: In patients with advanced heart failure, echocardiographic RAP prediction methods showed only modest precision. Furthermore, none of the tested methods resulted in clinically relevant improvements of RAP estimates. Estimating RAP from a single IVCd measurement is at least as precise as using complex prediction methods. (J Am Soc Echocardiogr 2014;27:1072-8.)

Keywords: Right atrial pressure, Right atrial pressure estimation, Inferior vena cava diameter, Central venous pressure, CVP

Right atrial pressure (RAP) estimation is an integral part of a standard echocardiographic examination. It is particularly relevant in patients with acute worsening of heart failure, in whom clinical assessment of volume status is often difficult. Estimation of RAP is also relevant in evaluating pulmonary hemodynamics in a wide range of circumstances, as estimating pulmonary artery pressures and right ventricular (RV) systolic pressure (RVSP) requires an estimate of RAP along with the measurement of peak tricuspid regurgitant velocity.[1,2]

Most frequently used methods of RAP assessment by echocardiography rely on inferior vena cava (IVC) diameter (IVCd) quantification, as IVCd and its changes have been shown to correlate with RAP,[3] and in the modern era, with the advent of portable echocardiographic devices, it is possible to rapidly assess IVCd even at the bedside. Unfortunately, accurate estimation of RAP by IVCd may be technically challenging.[4] Thus, in an attempt to better estimate RAP, several different methods, using various two-dimensional, Doppler, and tissue Doppler parameters and their combination, have been proposed. However, there is a lack of data on how well these methods compare with one another, especially in the setting of symptomatic heart failure.

The aim of this study was to validate previously proposed methods of RAP estimation in a prospective cohort of patients with acute decompensated heart failure. We also assessed whether RAP estimation can be improved by a statistically optimized combination of its echocardiographic predictors.

From the Heart and Vascular Institute, Cleveland Clinic, Cleveland, Ohio.

This publication was made possible by the Clinical and Translational Science Collaborative of Cleveland, Grant No. UL1TR000439 from the National Center for Advancing Translational Sciences of the National Institutes of Health, and the National Institutes of Health Roadmap for Medical Research. Mr Borowski was funded by an American Society of Echocardiography sonographers' grant.

Reprint requests: Zoran B. Popović, MD, PhD, Heart and Vascular Institute, Department of Cardiovascular Medicine, Cleveland Clinic, 9500 Euclid Avenue, Desk J1-5, Cleveland, OH 44195 (E-mail: *popoviz@ccf.org*).

0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2014.06.002

Abbreviations
CART = Classification and regression tree
IVC = Inferior vena cava
IVCd = Inferior vena cava diameter
$IVCd_{Insp}$ = Inferior vena cava diameter during sniff
IVCd%change = Percentage change in inferior vena cava diameter
RAEF = Right atrial emptying fraction
RAP = Right atrial pressure
RAVI = Right atrial volume index
RVSP = Right ventricular systolic pressure
S/D_{hep} = Hepatic flow S/D ratio
SEE = Standard error of the estimate
TR = Tricuspid regurgitation

METHODS

Study Population and Design

This was a prospective observational echocardiographic study of patients admitted to the Heart Failure Unit at the Cleveland Clinic for hemodynamically tailored treatment of acute decompensated systolic heart failure. We prospectively identified patients aged ≥18 years who were admitted to the heart failure intensive care unit at the Cleveland Clinic for pulmonary catheter–based therapy for acute decompensated systolic heart failure. The decision to treat patients in the intensive care unit was made on the basis of their initial left ventricular and RV filling pressures. Subjects were included in this study if they met the following criteria: (1) impaired systolic function, defined by a left ventricular ejection fraction ≤ 35% for ≥6 months; (2) elevated filling pressures, defined as a pulmonary capillary wedge pressure > 18 mm Hg or a central venous pressure > 8 mm Hg; and (3) New York Heart Association functional class III or IV symptoms. The exclusion criteria were (1) mechanical ventilation, (2) chronic dialysis, (3) cardiac transplantation, and (4) tricuspid valve surgery. The Cleveland Clinic Institutional Review Board approved our study project, and oral and written informed consent was obtained from all subjects.

Hemodynamic data acquisition was immediately followed by echocardiographic data acquisition, within 12 hours of admission (baseline) and after 48 to 72 hours of intensive medical therapy. Central venous pressure data were collected using a standard fluid-filled balloon-tipped pulmonary artery catheter, using the average of five cycles after balancing the transducer to the zero level at the midaxillary line. Central venous pressure was assessed at end-expiration with the patient in a supine position by an observer unaware of the echocardiographic measurements. Central venous pressure was equivalent to that of RAP.

Transthoracic Echocardiography

Comprehensive two-dimensional echocardiography was performed at the bedside with a commercially available system. Standard two-dimensional and Doppler echocardiographic images were acquired with the patient in the supine position using a phased-array transducer in the parasternal, apical, and subcostal views and with the patient in the lateral decubitus position when acquiring tricuspid annular and tricuspid inflow velocities. Three consecutive cardiac cycles were recorded and stored for subsequent offline analysis by two independent investigators experienced with echocardiographic measurements. All echocardiographic data were acquired in end-expiration except for IVCd, which was also performed during sniff ($IVCd_{Insp}$). All investigators were unaware of the time of registration and the identity of subjects.

Data Analysis

IVCd was measured from the long-axis subxiphoid view between 5 and 30 mm^5 from the IVC and right atrial junction during end-expiration in the supine position.[1] IVCd measurements were repeated during sniff.[1]

The percentage change in IVCd (IVCd%change) was calculated as $IVCd_{Insp}/IVCd \times 100\%$.[5] Right atrial volume index (RAVI) and right atrial emptying fraction (RAEF) were calculated from the apical four-chamber view images at end-systole and end-diastole using Simpson's method in the four-chamber view at both time points.[6,7] RAEF was calculated by two-dimensional echocardiography as $1 - RAVI_s/RAVI_d$, where subscripts s and d indicate systole and diastole, respectively.[8]

In patients in sinus rhythm, we calculated the ratio between peak early diastolic velocities obtained from the pulsed Doppler signal of tricuspid inflow (E) and the pulsed tissue Doppler signal of the lateral tricuspid annulus imaged in the apical four-chamber view (E'_{ta}) and the ratio between the E-wave and atrial-wave velocities of the tricuspid inflow (RV E/A ratio).

The ratio between the systolic and diastolic velocities of hepatic flow (S/D_{hep}) was calculated from the pulsed Doppler signal. The RV Tei index was calculated as $(D - S)/S$, where D is the time interval between the end and onset of tricuspid annular diastolic velocity, and S is the duration of tricuspid annular systolic velocity or RV ejection time.[9]

RV regional isovolumic relaxation time was assessed by measuring the time interval between the end of systolic annular motion and the onset of the E′ wave in the apical four-chamber view.[10] RVSP was determined by adding an estimate of RAP to 4 times the square of the peak tricuspid regurgitation (TR) velocity (expressed in meters per second) and the RAP estimated by method 1 (see below).

TR was graded semiquantitatively on a five-point scale (0 = none, 1 = mild, 2 = moderate, 3 = moderately severe, 4 = severe).

RV systolic function was determined by evaluating RV fractional area change (<35% represents dysfunction), peak systolic velocity of the tricuspid annulus (<10 cm/sec represents dysfunction), and tricuspid annular plane systolic excursion obtained by M-mode echocardiography (≤1.5 cm repsresents dysfunction).[2]

Assessment of RAP

RAP was estimated by three proposed methods as follows.

Method 1. Using the cutoffs defined by IVCd and IVCd%change during inspiration[11]:

- If IVCd < 1.5 cm, RAP = <5 mm Hg
- If IVCd = 1.5 to 2.5 cm and IVCd%change > 50%, RAP = 5 to 10 mm Hg
- If IVCd = 1.5 to 2.5 cm and IVCd%change < 50%, RAP = 10 to 15 mm Hg
- If IVCd > 2.5 cm and IVCd%change > 50%, RAP = 15 to 20 mm Hg
- If IVCd > 2.5 cm and IVCd%change < 50%, RAP = >20 mm Hg

Method 2. Using IVCd%change and S/D_{hep}[12]:

- If IVCd%change > 50% and $S/D_{hep} > 1$, RAP = 0 to 5 mm Hg
- If IVCd%change > 50% and $S/D_{hep} < 1$, RAP 5 to 10 mm Hg
- If IVCd%change < 50% and $S/D_{hep} < 1$, RAP = 10 to 15 mm Hg
- If IVCd%change < 50% and $S/D_{hep} > 1$, RAP = > 15 mm Hg