Reappraisal of the Use of Inferior Vena Cava for Estimating Right Atrial Pressure

J. Matthew Brennan, MD, John E. Blair, MD, Sascha Goonewardena, MD, Adam Ronan, MD, Dipak Shah, MD, Samip Vasaiwala, MD, James N. Kirkpatrick, MD, and Kirk T. Spencer, MD, *Chicago, Illinois*

Estimation of right atrial pressure (RAP) using echocardiographic measurement of the inferior vena caval (IVC) size along with its respirophasic variation is commonly performed despite the paucity of data that critically evaluates this technique. In this study, we systematically evaluated echocardiographic imaging of the IVC for estimation of RAP in 102 patients undergoing right heart catheterization. This study established cut-off values using receiver operating characteristic analysis for 8 different IVC parameters and then prospectively tested these parameters for their ability to predict an elevated RAP. The IVC size cutoff with optimum predictive use for RAP above or below 10 mm Hg was 2.0 cm (sensitivity 73% and specificity 85%) and the optimal IVC collapsibility cutoff was 40% (sensitivity 73% and specificity 84%). Traditional classification of RAP into 5-mm Hg ranges based on IVC size and collapsibility performed poorly (43% accurate) and a new classification scheme is proposed. (J Am Soc Echocardiogr 2007;20:857-861.)

Examination of the jugular venous pulse (JVP) to estimate right atrial (RA) pressure (RAP) is a commonly performed bedside technique. Detection of an elevated JVP in patients with left heart failure predicts an elevated pulmonary capillary wedge pressure and portends a poor prognosis.[1,2] However, the JVP is often difficult to accurately ascertain because of patient body habitus or poor examiner technique. Even when it is visualized, there is a poor correlation between JVP estimation of RAP and invasive measurements.[3-7] As such, there is a need for a reliable noninvasive technique for determination of RAP.

Ultrasound estimation of RAP has been performed using M-mode, Doppler, and 2-dimensional echocardiography. Hepatic vein systolic filling fraction assessed by pulsed wave Doppler correlates with RAP.[8] However, the most commonly used technique involves measurement of the inferior vena caval (IVC) size along with its respirophasic variation.[8-18] Multiple studies have demonstrated fair to excellent correlation between RAP and a variety of IVC parameters.[8,9,11-16,18] However, when estimating the RAP in a specific patient, it is the predictive accuracies of a parameter that matter, rather than correlation, which involves assessment of a group of patients.

From the University of Chicago.

Reprint requests: Kirk T. Spencer, MD, University of Chicago, 5841 S Maryland, A700, Chicago, IL 60637 (E-mail: *kspencer@uchicago.edu*).

0894-7317/$32.00

doi:10.1016/j.echo.2007.01.005

Far fewer studies have evaluated the accuracy of IVC parameters for assessment of RAP.[8,11-13] Among these studies, the cutoffs for predicting an elevated RAP have varied and no study has evaluated all the IVC variables in a single patient group. In addition, only one study has evaluated the receiver operating characteristic (ROC) of the parameters to determine appropriate cutoffs and this was done for a single parameter.[11] Lastly, comparison of the performance of various IVC parameters is confounded by the different studies, which use a variety of definitions for what constitutes an elevated RAP.

In this study, we systematically evaluated echocardiographic imaging of the IVC for estimation of RAP in patients undergoing right heart catheterization. Specifically, we sought to define cutoffs using ROC curves for all parameters and then prospectively test these parameters for their ability to predict an elevated RAP.

METHODS

Our institutional review board approved the protocol. In all, 102 patients referred for right heart catheterization at our institution were enrolled. The patients were divided into two groups: the first used to derive cut-off points (derivation group) and the second to validate them in a test population (test group). The patients were selected consecutively without regard for their medical history or the quality of their echocardiographic images. Baseline patient demographics including age, sex, and body surface area (BSA) were recorded.

Right heart catheterization was performed using flow-directed pulmonary artery catheters. After obtaining central venous access, the catheter was advanced into the RA where RAP was transduced after proper zeroing and calibration. In all, 5 to 10 cardiac cycles were acquired and mean RAP calculated using a standard hemodynamic software package (Mac-Lab, GE Medical Systems Information Technologies, Chalfont, St. Giles, UK).

Patients underwent a brief echocardiographic examination (Optigo, Philips Medical, Eindhoven, The Netherlands) focused on the IVC. The IVC was assessed with the patient in the supine position on a cot in the holding area within 1 hour of precatheterization or postcatheterization. Measurements were taken immediately before catheterization for patients scheduled to receive IV contrast. Taking care to maximize the IVC diameter throughout the respiratory cycle, the maximum IVC diameter ($IVCD_{max}$) and minimum IVC diameter ($IVCD_{min}$) during passive respiration within 2.0 cm of the IVC-RA junction were measured. Patients were then asked to perform a brief rapid inspiration or sniff and additional 2-dimensional loops were recorded. The IVC diameter was then measured as the smallest IVC size recorded during the sniff ($IVCD_{sniff}$). All values constitute the average of 3 measurements.

Data Analysis

All IVC linear measurements were indexed by dividing by BSA. The IVC collapsibility index ($IVCCI_{min}$) was calculated using the formula: $[(IVCD_{max} - IVCD_{min})/IVCD_{max}] \times 100$. The $IVCCI_{sniff}$ was calculated by substituting $IVCD_{sniff}$ for $IVCD_{min}$ in the IVCCI formula.

A RAP of 10 mm Hg or greater was chosen to represent a clinically significant elevation in RAP.[11,12,19] ROC curves were generated using data obtained from the derivation group to determine optimal cutoffs for prediction of RAP greater than or equal to 10 mm Hg or less than 10 mm Hg. The sensitivity, specificity, negative predictive value, positive predictive value, and accuracies were computed in the test group of patients in the usual fashion. Pearson correlation coefficients and contingency tables were used for data analysis.

RESULTS

Study Population

In all, 102 patients were enrolled (50 derivation group; 52 test group). Eleven patients had inadequate IVC examinations (5 in derivation group and 6 in test group). Indications for right heart catheterization included: postcardiac transplant evaluation (30%), pulmonary hypertension (29%), congestive heart failure (32%), and other (11%, valvular heart disease, preliver transplant, constriction, pericardial effusion). Of the patients, 9% were in atrial fibrillation. Demographic data along with average values for the IVC parameters and RAP are listed in Tables 1 and 2. Each IVC parameter had a modest correlation with RAP, ranging from 0.46 to 0.63 (Table 2).

Table 1 Patient demographics (n = 102)

Patient characteristic	Mean ± SD
Age	50 ± 17
Male	55%
Weight, kg	85 ± 29
Height, cm	172 ± 11
BSA, m^2	2.0 ± 0.3
Ultrasound window	
Inadequate	11%
Adequate	89%

BSA, Body surface area.

Table 2 Inferior vena cava and right heart catheterization parameters (all patients)

Echocardiographic data	Mean ± SD	Correlation with RAP
$IVCD_{max}$	1.8 ± 0.5 cm	0.50
$IVCD_{min}$	1.2 ± 0.6 cm	0.60
$IVCD_{sniff}$	0.9 ± 0.7 cm	0.63
$IVCD_{max}$/BSA	0.9 ± 0.3 cm/m2	0.46
$IVCD_{min}$/BSA	0.7 ± 0.4 cm/m2	0.57
$IVCD_{sniff}$/BSA	0.5 ± 0.4 cm/m2	0.61
$IVCCI_{min}$	33% ± 22%	−0.50
$IVCCI_{sniff}$	52% ± 28%	−0.54
RHC data		
RAP (mmHg)	7.0 ± 7.1	

BSA, Body surface area; *IVCCI*, inferior vena caval collapsibility index; *RAP*, right atrial pressure; *RHC*, right heart catheterization.

Table 3 Receiver operating characteristic curves for predicting right atrial pressure greater than 10 mm Hg

	Evaluation group (N = 45)	
Parameter	AUC	Cutoff
$IVCD_{max}$	0.76	2.0 cm
$IVCD_{min}$	0.88	1.5 cm
$IVCD_{sniff}$	0.92	1.2 cm
$IVCD_{max}$/BSA	0.73	1.1 cm/m2
$IVCD_{min}$/BSA	0.85	0.7 cm/m2
$IVCD_{sniff}$/BSA	0.92	0.6 cm/m2
$IVCCI_{min}$	0.93	20%
$IVCCI_{sniff}$	0.91	40%

AUC, Area under receiver operating characteristic curve; *BSA*, body surface area; *cutoff*, parameter value for optimal performance.

Determination of Discriminate Values for Predicting an Elevated RAP

The ROC curves created from the derivation patient group demonstrated that all of the IVC parameters had at least fair discriminate ability (Table 3). The two collapsibility indices had the best area under the curve (AUC) and the $IVCD_{max}$ dimension had a somewhat lower, although still fair AUC. Indexing the IVC measurements by BSA did not improve the AUC. There was no significant difference in the AUC whether the IVCCI was computed during passive respiration or with inhalation (sniff). The $IVCD_{max}$

Table 4 Performance of inferior vena cava parameters in this study and prior literature

Reference	Variable	N	Cutoff	RAP	Sen	Spec	PPV	NPV	Acc
Current	$IVCD_{max}$	46	2.0	10	73	85	62	90	82
13	$IVCD_{max}$	65	2.3	7	40	97	93	58	66
Current	$IVCD_{min}$	46	1.5	10	91	79	59	96	82
Current	$IVCD_{sniff}$	46	1.2	10	91	94	83	97	93
Current	$IVCD_{max}$/BSA	46	1.1	10	82	85	64	93	84
Current	$IVCD_{min}$/BSA	46	0.7	10	91	79	59	96	82
12	$IVCD_{min}$/BSA	111	1.0	10			94		
Current	$IVCD_{sniff}$/BSA	46	0.6	10	91	88	71	97	88
Current	$IVCCI_{min}$	46	20	10	73	82	57	90	80
13	$IVCCI_{min}$	65	40	7	91	90	91	90	91
Current	$IVCCI_{sniff}$	46	40	10	73	84	62	90	81
8	$IVCCI_{sniff}$	23	50	8	72	76			
11	$IVCCI_{sniff}$	83	50	10	87	82			88
19	$IVCCI_{sniff}$	20	50	10	87	100	100	92	

Acc, Accuracy; *BSA*, body surface area; *NPV*, negative predictive value; *PPV*, positive predictive value; *RAP*, right atrial pressure; *sen*, sensitivity; *spec*, specificity.

Table 5 Classification of right atrial pressure

Collapsibility	High	High	High	NL	NL	NL	Low	Low	Low
Size, cm	Small	NL	Big	Small	NL	Big	Small	NL	Big
No. of patients	25	12	2	3	17	4	7	6	10
Mean RAP, mm Hg	3.4	3.3	4.5	4.3	6.1	12	11	12	17
0-5 mm Hg, %	84	100	50	67	47	0	29	33	0
5-10 mm Hg, %	12	0	50	33	35	0	29	0	20
10-15 mm Hg, %	4	0	0	0	18	75	0	33	50
>15 mm Hg, %	0	0	0	0	0	25	43	33	30
Traditional RAP classification, mm Hg	0-5	5-10	–	0-5	5-10	–	–	10-15	15-20
Suggested RAP classification, mm Hg	0-5	0-5	0-10	0-10	0-10	10-15	I	I	10-20

I, Indeterminate; *mean RAP*, mean right atrial pressure (RAP) of patients in each subgroup; *suggested RAP*, recommendation for RAP range that patients within each subgroup would best be classified to have maximal accuracy; *traditional RAP*, RAP range patient with specific subgroup's inferior vena caval collapsibility and size would be assigned according to current guidelines.
All patients were segregated into 1 of 9 subgroups depending on whether their collapsibility was high (>55%), low (<35%), or normal (35%-50%) and their inferior vena cava small (<1.7 cm), normal (1.7-2.1 cm), or large (>2.1 cm).

size cutoff with optimum predictive use for RAP above or below 10 mm Hg was 2.0 cm and the optimal $IVCCI_{sniff}$ cutoff was 40%.

Evaluation of Discriminate Values to Predict an Elevated RAP in the Test Group

In the test group of patients, a maximal IVC size cutoff of 2 cm had good sensitivity (73%) and specificity (85%) for predicting RAP greater than 10 mm Hg (Table 4). The IVC minimal size during passive respiration had similar accuracy whereas the minimal IVC size with sniff had somewhat higher sensitivity and specificity. The most notable finding is that the IVC size measurements had an excellent negative predictive value. A RAP greater than 10 mm Hg was infrequently found when $IVCD_{min}$ was less than 1.5 cm or $IVCD_{sniff}$ was less than 1.2 cm. Indexing the IVC size parameters by BSA did not yield a significant improvement in accuracy.

The collapsibility index cutoffs with optimum predictive use for RAP greater than 10 mm Hg were 20% with passive respiration and 40% after sniff (Table 3). Although these two parameters had among the best AUC in the initial group of patients, they performed at the lower end in the test group with accuracies of 80% to 81%. The collapsibility indices, like the IVC size parameters, yielded excellent negative predictive values. There was only a small improvement in the test performance when $IVCD_{sniff}$ rather than $IVCD_{min}$ was used to predict RAP. Accuracies of all parameters were similar in the patients with cardiac transplantation.

Accuracy of IVC Parameters to Classify RAP into Ranges

All patients were categorized by $IVCD_{max}$ and $IVCCI_{sniff}$ into one of 9 subgroups (Table 5). The mean RAP was calculated for each subgroup and the percentage of patients falling within the traditional RAP ranges of 0 to 5, 5 to 10, 10 to 15, and greater than 15 mm Hg were determined. Each categorization had at least two patients and a small IVC with high IVCCI was the most common (n = 25). Within each classification of size, there was an increase in mean RAP as collapsibility decreased. On the contrary, when grouped by IVCCI, there was no significant change in mean RAP between patients with small or normal-sized IVCs.

The majority of the subgroups (8/9) did not classify patients into a single 5-mm Hg RAP range. For at least 75% of the patients to be included, at least two RAP ranges were most often required. When collapsibility was high and IVC size was small or normal, RAP was between 0 and 5 mm Hg 92% of the time. When collapsibility was high with a large IVC or collapsibility was normal and IVC size was small or normal, RAP was between 0 and 10 mm Hg 87% of the time. If collapsibility was normal and the IVC was big, RAP was between 10 and 15 mm Hg. On the other hand, if the IVC was big with low collapsibility the RAP was most likely 10 to 20 mm Hg. Low collapsibility with small or normal-sized IVCs revealed no consistent pattern with patients who had RAP less than 5 mm Hg and greater than 15 mm Hg.

DISCUSSION

Despite the widespread use of IVC size and respirophasic size change for estimation of RAP in clinical echocardiographic laboratories, there is a paucity of data that critically evaluates the commonly used cutoffs or compares which parameters are most accurate.[8-18] Multiple studies have demonstrated fair to excellent correlations, similar to those seen in this study, between RAP and a variety of IVC parameters.[8,9,11-16,18] However, identification of the most accurate parameter for predicting a given patient's RAP when interpreting their echocardiogram is best evaluated by accuracy and predictive power, not correlation values.

Of the 8 parameters evaluated in this study, no variable clearly outperformed any of the others. Among the different measures of IVC size, $IVCD_{sniff}$ had the highest accuracy. However, as $IVCD_{max}$ also performed well it is preferred, as finding and maintaining an image the $IVCD_{max}$ is both easiest and most familiar. The lower sensitivity (40%) and higher specificity (97%) previously reported for $IVCD_{max}$ are readily explained by the lower cutoff for an elevated RAP used in that study (7 mm Hg) and the larger $IVCD_{max}$ cutoff of 2.3 cm.[13] There are reasons to expect that indexing IVC size by BSA would improve accuracy but this was not observed.

It is clear when classifying RAP that IVC collapsibility adds to the assessment of IVC size. Using a device capable of measuring inspiratory effort, investigators have demonstrated that the inspiratory effort required to collapse the IVC 85% is strongly and linearly correlated to mean RAP.[18] There are practical reasons to expect that $IVCCI_{sniff}$ might outperform $IVCCI_{min}$. In patients passively breathing there can be minimal respirophasic change in the IVC diameter. This may represent significant elevation in RAP or simply insufficient respiratory effort to collapse the IVC in the setting of a normal RAP. These scenarios can be distinguished by having the patient take a brief rapid inspiratory effort or sniff.

The $IVCCI_{sniff}$ specificity of 84% is similar to other reports (76% and 82%).[8,11] A third study reported a specificity of 100% but included only 20 patients.[19] The $IVCCI_{sniff}$ sensitivity of 73% is similar to a prior report (72%),[8] but lower than two others (both 87%).[11,19] The prior studies used a higher $IVCCI_{sniff}$ cutoff, which would be expected to improve sensitivity. More importantly, the only study to use ROC analysis to determine the proper cutoff for IVCCI reported the sensitivity and specificity in the same group from which the discriminate values were derived. It is clear that this method provides accuracy results that represent the best-case scenario.

In addition to classifying RAP in a binary fashion as above or below 10 mm Hg, it is clinically helpful to assign RAP into a range. Using cutoffs for $IVCD_{max}$ and $IVCCI_{sniff}$, several different methods have been proposed to categorize RAP into one of the ranges: 0 to 5, 5 to 10, 10 to 15, and greater than 15 mm Hg.[20-23] Although this method is commonly used in clinical laboratories, the data supporting the accuracy of this are minimal and the accuracy of classification into these subgroupings of RAP has never been critically evaluated.

Several observations regarding RAP classification can be made from the data in this study. First, categories that do not exist by traditional classification such as small IVCs with low collapsibility and large IVCs with normal/high collapsibility do occur. In fact, these patients represented 15% of patients. Second, the percentage of time an individual patient was correctly classified using traditional criteria was only 43%.

Although clinically useful, it is impractical to expect the IVC criteria to accurately predict RAP within a narrow 5-mm Hg window. Other than when the IVC size is small/normal and collapsibility is high, which predicts RAP less than 5 mm Hg, most other classifications need a 10-mm Hg range to have sufficient predictive accuracy. When collapsibility is low and the IVC small or normal in size, RAP can range from less than 5 to greater than 15 mm Hg. This disparity likely reflects the limitation of the sniff technique. That is, some patients with low collapsibility and an IVC that is small/normal in size truly have significant elevation of RAP. However, many of these patients have normal of even low RAP and probably do not take a strong enough sniff to collapse their IVC.

These data would suggest 5 different RAP classifications based on IVC size and collapsibility (Table 5). (1) High collapsibility with a small or normal-sized IVC; RAP is very likely low (<5 mm Hg). (2) High collapsibility with a large IVC or normal collapsibility with a small/normal-sized IVC; RAP is probably between 0 and 10 mm Hg. (3) Normal collapsibility with large IVC; RAP is 10 to 15 mm Hg. (4) Low collapsibility with a large IVC; RAP is clearly high (10-20 mm Hg). (5) RAP in patients with low collapsibility and a normal-sized or small IVC should be interpreted as indeterminate.

Limitations

The patients in the study were all referred for a clinically indicated right heart study and may differ from a population of patients referred for echocardiography. A significant proportion of the patients were postcardiac transplantation (30%), this may affect the generalizability of the data, although subgroup analysis was similar in this group. The echocardiographic acquisition in this study was limited to the IVC, thus, complete echocardiographic data were not acquired. This prevents assessment of confounding factors that might affect IVC size and respirophasic change (tricuspid regurgitation) or assessment of the additive value of other echocardiographic parameters (hepatic vein Dopplers).

Conclusion

This is the first study to determine cutoffs through ROC analysis for 8 parameters of IVC size and collapsibility and then prospectively test these cutoffs to predict elevated RAP. The IVC size cutoff with optimum predictive use for RAP above or below 10 mm Hg was 2.0 cm (sensitivity 73% and specificity 85%) and the optimal IVC collapsibility cutoff was 40% (sensitivity 73% and specificity 84%). All parameters had excellent negative predictive ability. Critical evaluation of the traditional classification of RAP into narrow 5-mm Hg ranges based on IVC size and collapsibility demonstrates significant limitations and suggestions for a more accurate categorization are provided.

REFERENCES

1. Drazner MH, Rame JE, Stevenson LW, Dries DL. Prognostic importance of elevated jugular venous pressure and a third heart sound in patients with heart failure. N Engl J Med 2001;345:574-81.
2. Stevenson LW. Are hemodynamic goals viable in tailoring heart failure therapy? Hemodynamic goals are relevant. Circulation 2006;113:1020-7.
3. Chan KL, Currie PJ, Seward JB, Hagler DJ, Mair DD, Tajik AJ. Comparison of three Doppler ultrasound methods in the prediction of pulmonary artery pressure. J Am Coll Cardiol 1987;9:549-54.
4. Currie PJ, Seward JB, Chan KL, et al. Continuous wave Doppler determination of right ventricular pressure: a simultaneous Doppler-catheterization study in 127 patients. J Am Coll Cardiol 1985;6:750-6.
5. Demeria DD, MacDougall A, Spurek M, et al. Comparison of clinical measurement of jugular venous pressure versus measured central venous pressure. Chest 2004;126:747S.
6. Eisenberg PR, Jaffe AS, Schuster DP. Clinical evaluation compared to pulmonary artery catheterization in the hemodynamic assessment of critically ill patients. Crit Care Med 1984;12:549-53.
7. Stein JH, Neumann A, Marcus RH. Comparison of estimates of right atrial pressure by physical examination and echocardiography in patients with congestive heart failure and reasons for discrepancies. Am J Cardiol 1997;80:1615-8.
8. Nagueh SF, Kopelen HA, Zoghbi WA. Relation of mean right atrial pressure to echocardiographic and Doppler parameters of right atrial and right ventricular function. Circulation 1996; 93:1160-9.
9. Goldberger JJ, Himelman RB, Wolfe CL, Schiller NB. Right ventricular infarction: recognition and assessment of its hemodynamic significance by two-dimensional echocardiography. J Am Soc Echocardiogr 1991;4:140-6.
10. Himelman RB, Kircher B, Rockey DC, Schiller NB. Inferior vena cava plethora with blunted respiratory response: a sensitive echocardiographic sign of cardiac tamponade. J Am Coll Cardiol 1988;12:1470-7.
11. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. Am J Cardiol 1990;66:493-6.
12. Mintz GS, Kotler MN, Parry WR, Iskandrian AS, Kane SA. Real-time inferior vena caval ultrasonography: normal and abnormal findings and its use in assessing right-heart function. Circulation 1981;64:1018-25.
13. Moreno FL, Hagan AD, Holmen JR, Pryor TA, Strickland RD, Castle CH. Evaluation of size and dynamics of the inferior vena cava as an index of right-sided cardiac function. Am J Cardiol 1984;53:579-85.
14. Nakao S, Come PC, McKay RG, Ransil BJ. Effects of positional changes on inferior vena caval size and dynamics and correlations with right-sided cardiac pressure. Am J Cardiol 1987;59:125-32.
15. Ommen SR, Nishimura RA, Hurrell DG, Klarich KW. Assessment of right atrial pressure with 2-dimensional and Doppler echocardiography: a simultaneous catheterization and echocardiographic study. Mayo Clin Proc 2000;75:24-9.
16. Pepi M, Tamborini G, Galli C, et al. A new formula for echo-Doppler estimation of right ventricular systolic pressure. J Am Soc Echocardiogr 1994;7:20-6.
17. Randazzo MR, Snoey ER, Levitt MA, Binder K. Accuracy of emergency physician assessment of left ventricular ejection fraction and central venous pressure using echocardiography. Acad Emerg Med 2003;10:973-7.
18. Simonson JS, Schiller NB. Sonospirometry: a new method for noninvasive estimation of mean right atrial pressure based on two-dimensional echographic measurements of the inferior vena cava during measured inspiration. J Am Coll Cardiol 1988;11:557-64.
19. Vourvouri EC, Schinkel AF, Roelandt JR, et al. Screening for left ventricular dysfunction using a hand-carried cardiac ultrasound device. Eur J Heart Fail 2003;5:767-74.
20. Lang RM, Bierig M, Devereux RB, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's guidelines and standards committee and the chamber quantification writing group. J Am Soc Echocardiogr 2005;18:1440-63.
21. Otto CM. The practice of clinical echocardiography. 2nd ed. Philadelphia: WB Saunders; 2002.
22. Otto CM. Textbook of clinical echocardiography. 3rd ed. Philadelphia: WB Saunders; 2004.
23. Vannan MA, Lang RM, Rakowski H, Tajik AJ. Atlas of echocardiography. Philadelphia: Current Medicine LLC; 2005.