Noninvasive Evaluation of Right Atrial Pressure

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In current practice, right atrial pressure (RAP) is an essential component in the hemodynamic assessment of patients and a requisite for the noninvasive estimation of the pulmonary artery pressures. RAP provides an estimation of intravascular volume, which is a critical component for optimal patient care and management. Increased RAP is associated with adverse outcomes and is independently related to all-cause mortality in patients with cardiovascular disease. Although the gold standard for RAP evaluation is invasive monitoring, various techniques are available for the noninvasive evaluation of RAP. Various echocardiographic methods have been suggested for the evaluation of RAP, consisting of indices obtained from the inferior vena cava, systemic and hepatic veins, tissue Doppler parameters, and right atrial dimensions. Because the noninvasive evaluation of RAP involves indirect measurements, multiple factors must be taken into account to provide the most accurate estimate of RAP. The authors review the data supporting current guidelines, identifying areas of agreement, conflict, limitation, and uncertainty. (J Am Soc Echocardiogr 2013;26:1033-42.)

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The terms "central venous pressure" (CVP) and "right atrial pressure" (RAP) are synonymous as long as no obstruction of the vena cava is present. The gold standard for the evaluation of RAP is invasive monitoring using a central venous catheter. Yet this is an invasive method not without risks[1-3] and is thus not practical for widespread appli-cation. The normal range for RAP is between 1 and 7 mm Hg.[4] Elevated values have prognostic implications for both morbidity and mortality,[5-8] making the accurate assessment of RAP a determining factor in patient assessment, management, and outcomes.[9,10] The noninvasive evaluation of RAP, also a crucial component of the noninvasive estimation of the pulmonary artery pressures, includes the physical examination along with Doppler echocardiographic indices.

PHYSICAL EXAMINATION

Jugular Venous Pressure (JVP)

Sir Thomas Lewis, in 1930, first proposed the determination of a patient's venous pressure during the physical examination.[11] Lewis observed that the top of the jugular veins of normal individuals and the vertical distance from the top of the fluid in the manometer (which was used at that time to measure CVP) always came to lie within 1 to 2 cm of the sternal angle. Currently, examination of JVP is the mainstay of the bedside estimation of CVP.[5,12,13]

Evaluation of CVP using the jugular veins is preferably done using the right-sided jugular vein, which is in direct line with the right atrium, and clinical assessment of CVP on the left may be marginally higher than that on the right.[14] Both the external jugular vein and the internal jugular vein (IJV) can be used for evaluation. Although the external jugular vein is easier to visualize, the IJV is preferred because it does not have valves and is in line with the superior vena cava (SVC) and the right atrium.[15] The patient should be recumbent with the head elevated at 30° to 45°. The level of venous pressure is estimated by identifying the highest point of oscillation of the jugular vein (which occurs during the expiratory phase of respiration). This level is then related to the middle of the right atrium, where venous pressure is, by convention, zero. A reliable substitute is the angle of Louis at the junction of the manubrium and the body of the sternum, located 5 cm above the middle of the right atrium (in approximation for practical purposes). The vertical distance (in centimeters) from the sternal angle to the top of the jugular venous wave represents the JVP (Figure 1); thus, CVP equals JVP + 5 cm.[14] Because the clavicle lies vertically 2 cm above the sternal angle, only a CVP of 7 cm will be observed. JVP estimation may be inaccurate if the jugular vein is constricted or torturous, and it might be difficult to assess in patients with short necks, with prior neck surgery, or with prior catheter placement in the jugular vein.

The Abdominojugular Reflux

The test consists of assessing JVP before, during, and after abdominal compression. It is performed with firm pressure of 20 to 30 mm Hg applied to the midabdomen for 10 to 30 sec.[16] The CVP of normal individuals usually remains unchanged or does not increase by >4 cm for a beat or two (usually for <10 sec), or it may fall slightly.[16,17] If the CVP rises by >4 cm and stays elevated throughout the maneuver, this correlates with elevated RAP.[18] Reports suggest that a positive result is indicative of right ventricular (RV) failure or

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Abbreviations

ASE = American Society of Echocardiography

BSA = Body surface area

CVP = Central venous pressure

DTI = Doppler tissue imaging

IJV = Internal jugular vein

IVC = Inferior vena cava

JVP = Jugular venous pressure

RA = Right atrial

RAP = Right atrial pressure

RV = Right ventricular

SVC = Superior vena cava

3DE = Three-dimensional echocardiography

2DE = Two-dimensional echocardiography

VTI = Velocity-time integral

elevated pulmonary capillary wedge pressure.[16] However, if the patient strains (Valsalva maneuver) during the test, it may cause a false-positive result.

In general, the physical examination for the assessment of RAP has limited accuracy compared with invasive[19-24] or echocardiographic[25,26] studies, most commonly underestimating JVP[20-23] in the setting of elevated CVP.[23] Eisenberg *et al.*[19] found that after a baseline physical examination and assessment of CVP, catheter-derived CVP measurements differed significantly from those obtained on clinical examination in 50% of patients, and in 58% of these, the treatment plan was changed on the basis of the invasive assessment of CVP. Consequently the use of the physical examination might be best for categorizing CVP as either low to normal or elevated.

Doppler Echocardiography

Doppler echocardiography is routinely used to noninvasively estimate RAP. The Doppler echocardiographic methods to estimate RAP include assessment of the inferior vena cava (IVC), SVC, and hepatic vein indices of size and flow; Doppler systemic venous flow; tricuspid valve Doppler inflow; tricuspid valve tissue Doppler; and evaluation of right atrial (RA) dimensions. However, in uncommon circumstances, the flow into the right atrium and consequently the Doppler velocities may be affected by RA compression or distortion, as well as in the setting of RV inflow obstruction due to tumor or tricuspid stenosis. In these situations, assessing the tricuspid gradient can be useful for the estimation of RAP.

IVC Indices

The IVC is a highly compliant vessel, and consequently its size and dynamics vary with changes in CVP and volume. Blood flow from the superior and IVC into the right atrium is biphasic, with the largest forward flow occurring during ventricular systole. In general, there is a reciprocal relationship between pressure and flow; when flow increases (in the IVC as well as the right atrium), pressure decreases and vice versa. During inspiration (which produces negative intrathoracic pressure), vena cava pressure decreases and flow increases[27,28] (Figures 2A–2C). Because the vena cava acts as a capacitance reservoir, phasic increases in forward flow from the cava to the right atrium are accompanied by decreases in vena cava size. The smallest IVC dimension is seen during ventricular systole. At low or normal RAPs, there is systolic predominance in IVC flow, such that the systolic flow is greater than the diastolic flow. As RAP increases, it is transmitted to the IVC, resulting in blunting of the forward systolic flow, reduced IVC collapse with inspiration, and eventually IVC dilatation (Figures 2D–2F). The size and area of the IVC are affected by position

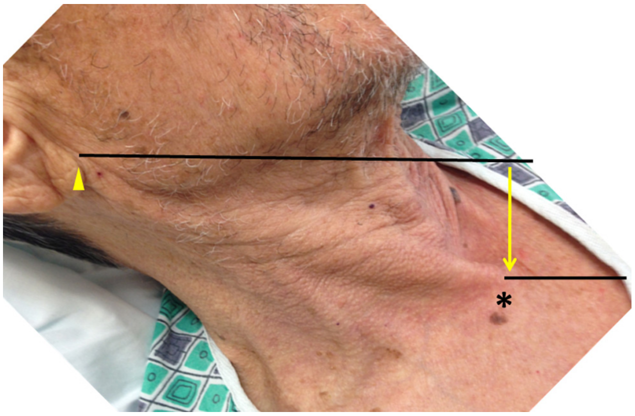

Figure 1 Evaluation of JVP. With the patient lying at about 45°, the highest point of pulsation of the jugular vein is identified (*arrowhead*). This is then related to the angle of Louis, found at the junction of the manubrium with the body of the sternum (*asterisk*). The vertical distance to the top of the jugular venous wave (*arrow*) can be determined and reported, in centimeters, as the JVP.

as well: IVC diameter and area are consistently largest when the patient is evaluated in the right lateral position, intermediate in the supine position, and smallest in the left lateral position.[29] Patient position, therefore, is an important factor to consider when correlating IVC size and shape with hemodynamic variables.

In 1979, Natori *et al.*[30] first described measuring IVC diameter and its change during respiration. Several studies have evaluated the correlation between RAP and different IVC parameters[30-41] (Table 1). However, fewer studies have evaluated the validity of the suggested IVC parameters for the accuracy of the estimation of RAP.[35,39,41] Most, but not all,[29,31] studies have demonstrated good correlations between the IVC collapsibility index ($[IVC_{max} - IVC_{min}]/IVC_{max}$) and RAP ($0.57 < r \leq 0.76$).[30,33-35,39] Although there is a correlation between IVC diameter and RAP ($0.72 < r \leq 0.86$),[29,31,35,40] some reports suggest that the correlation found between IVC diameter and RAP does not permit it to be used for the reliable estimation of RAP,[31,33] because of the variability and overlap between patients with normal RAPs and those with elevated RAPs. It is hypothesized that an increase of RAP beyond a certain level may cause only minimal increases in IVC diameter and the degree of IVC collapsibility with inspiration. Thus, IVC dimensions and collapsibility can be used to detect elevated CVP, but they have limited utility in identifying the magnitude of CVP elevation.

On the basis of several studies,[33,35,37] the American Society of Echocardiography (ASE) in 2005[42] recommended using maximal IVC diameter 1 to 2 cm from the junction of the right atrium and the IVC at end-expiration and the IVC collapsibility index to give an estimate of RAP. This measurement is best obtained from the subcostal view, with the IVC viewed in its long axis (Figure 2). Measurements should be made with the patient lying supine (because the left lateral position may underestimate maximal IVC diameter).[29] However, Brennan *et al.*[41] evaluated the 2005 ASE recommendations for assessing RAP[42] and found that only 43% of patients were correctly classified. On the basis of the results of their study, they suggested a new cutoff range that gives an estimation with range limits of 5–10 mm Hg (Table 2). The newer 2010 ASE guidelines[43] have been revised as noted in Table 2. These parameters yield more accurate results when estimating low or high RAP: IVC diameter < 2.1 cm and collapse > 50% correlates with a normal RAP of 0 to 5 mm Hg.