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Echocardiography in the use of noninvasive hemodynamic monitoring☆

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ABSTRACT

Invasive pulmonary artery catheter measurements are the standard method for assessment of hemodynamic evaluation at the present time. However, this invasive approach is associated with an increase in patient morbidity and without evidence of a reduction in mortality. Doppler echocardiography is a noninvasive method that provides robust data regarding patients' hemodynamic indices. Several parameters are available for noninvasive hemodynamic evaluation using Doppler echocardiography. Most of these measurements are easily obtained and provide a safe alternative to invasive hemodynamic assessment. As Doppler echocardiography is able to provide additional valuable information, such as cardiac systolic and diastolic function, and the presence of pericardial and pleural effusions, which can play a significant role in the patients' hemodynamic status, using this noninvasive modality in the daily practice for hemodynamic assessment can prove an alternative to invasive measures in selected patients as well as a complementary tool for those still in need of invasive monitoring.

Although pulmonary artery (PA) catheter measurements remain the criterion standard for hemodynamic evaluation at the present time, its routine use is controversial [1-3], as it has been associated with an increase in patient morbidity [4,5]. Echocardiography is an excellent diagnostic tool, which is readily available and can provide important information regarding several hemodynamic parameters. Various methods and parameters are available for noninvasive hemodynamic evaluation using Doppler echocardiography (Table 1). These measurements, discussed in this review, are easily obtained in most patients, providing a safe alternative to invasive assessment.

1. Central venous pressure

Accurate evaluation of the central venous pressure (CVP), which is equivalent to the right atrial pressure (RAP), is an essential component in the hemodynamic assessment of patients and a requisite for the noninvasive estimation of the PA pressures (Fig. 1).

1.1. Inferior vena cava parameters

The most commonly used echocardiographic method uses the inferior vena cava (IVC) size and its respiratory variation for the evaluation of RAP. The IVC is a highly compliant vessel; therefore, its size and flow dynamics vary with changes in CVP and volume. As shown in Fig. 1, during inspiration (which produces negative intrathoracic pressure), vena cava pressure decreases and flow increases [6,7]. At low or normal RAP, 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. For RAP assessment, an IVC with a diameter less than 2.1 cm and collapse greater than 50% correlates with a normal RAP of 0 to 5 mm Hg. An IVC less than 2.1 cm with less than 50% collapse and an IVC greater than 2.1 cm with greater than 50% collapse correspond to an intermediate RAP of 5 to 10 mm Hg. An IVC greater than 2.1 cm with less than 50% collapse suggests a high RAP of 15 mm Hg [8] (Table 1). Using midrange values of 3 mm Hg for normal and 8 mm Hg for intermediate RAP is recommended. However, if there is minimal collapse of the IVC (<35%) and/or secondary indices of elevated RAP are present (such as bulging of the interatrial septum toward the left ventricle (LV), increased right atrial [RA] dimensions, other indices suggestive of elevated RAP—see next) upgrading to the higher pressure limit (ie, 5 and 10 mm Hg in case of normal and intermediate RAP, respectively) should be done. Patients should be supine during assessment of the IVC as other positions may lead to either under or overestimation of IVC diameter and/or collapsibility [9]. Patients with low compliance with deep inspiration may have a diminished IVC collapse. In these cases, a “sniff” maneuver, which causes a sudden decrease in intrathoracic pressure hence accentuating the normal inspiratory response, can differentiate those with normal IVC collapsibility from those with a diminished IVC collapsibility.

The IVC can also be dilated in individuals with a normal RAP. A dilated IVC in the setting of normal RAP is commonly seen in athletes and in patients on mechanical ventilator support [10,11] as

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Table 1
Various methods used for the echocardiographic hemodynamic evaluation

Method	Criteria used	Comments
CVP/RAP		
IVC parameters—using subcostal imaging of the IVC	IVC dimensions: enlarged >2.1 cm IVCCI: Diminished <50% CVP/RAP categorized to: • Normal RAP ~3 mm Hg (IVC <2.1 cm; IVCCI >50%) • Intermediate RAP ~8* • Elevated RAP ~>15 mm Hg (IVC >2.1 cm, IVCCI <50%) —see also comments *In cases where the IVC diameter and collapse do not fit the normal or elevated criteria, the use of additional methods might allow for better estimation.	Most widely used method for evaluation of CVP/RAP Problematic in mechanically ventilated patients In situations of high RAP, the IVC may be fully dilated and not collapsing making estimation above a certain point difficult and unreliable
Venous flow pattern using Doppler estimation of flow in the vena cava, jugular, or hepatic veins	Vs > Vd – normal CVP/RAP Vs < Vd – elevated CVP/RAP (>8 mm Hg)	Not applicable in cases where there is severe TR, as this alters the systolic venous flow pattern Atrial fibrillation or past cardiac surgery can cause the hepatic vein systolic flow to be diminished regardless of RAP
Tricuspid inflow using Doppler and TDI of the tricuspid annulus	E/e' > 6: CVP/RAP >10 mm Hg	Found to be adequate in mechanically ventilated patients where IVC parameters might not be applicable May not be an accurate method in patients who have undergone cardiac surgery
SPAP		
Bernoulli equation with the TR maximal jet velocity (V)	$4 \times V^2 = \Delta P$; $\Delta P + CVP = SPAP$	Widely validated and simple method Easy to obtain in most patients Underestimation/overestimation of CVP can cause inaccuracies
Pulmonary flow acceleration time	<100 milliseconds indicates elevated SPAP	• Not widely studied • Validated only in patients with chronic heart failure Measurements can be affected by extremes of heart rate (60> and >100)
DPAP		
Bernoulli equation with the PR end diastolic jet velocity (V)	$4 \times V^2 = \Delta P$; $\Delta P + CVP = DPAP$	Not widely validated PR jet not always acquirable Underestimation/overestimation of CVP can cause inaccuracies
MPAP		
Bernoulli equation with the PR maximal jet velocity (V)	$4 \times V^2 = \Delta P$; $\Delta P + CVP = MPAP$	Not widely validated PR jet not always acquirable Underestimation/overestimation of CVP can cause inaccuracies
Tracing of the TR jet	Mean pressure gradient + CVP = MPAP	Easy to obtain in most patients Underestimation/overestimation of CVP can cause inaccuracies
Empirical formulas	MPAP = 0.61 SPAP + 2 mm Hg MPAP = DPAP + 1/3 (SPAP-DPAP)	Validated only invasively Validated using echocardiography in a single study
PVR		
Using empirical formulas	PVR (WU) = 10 × TR velocity/RVOT VTI + 0.16 PVRI = 1.97 + 190 × [SPAP/(HR × RVOT VTI)] SPAP/(HR × RVOT VTI) > 0.076 correlated with severe pulmonary vascular disease with PVRI > 15 WU/m^2	Not widely validated Evaluated in 1 study in patients with pulmonary hypertension
LA filling pressures/PCWP		
Mitral inflow parameters: E wave, A wave, DT, E/A ratio	Impaired LV relaxation: E/A < 1 or E/A > 2 DT prolonged >240 milliseconds Pseudonormal: 1<E/A<2, 160 < DT < 240 milliseconds Restrictive filling: E/A > 2, DT short < 160 milliseconds	* In young, healthy subjects some parameters can be similar as in those with disease. * Poor correlation in patients with coronary artery disease and those with hypertrophic cardiomyopathy with EF ≥ 50%
TDI combined with mitral inflow parameters	é, á E/é ratio < 8 – normal LV filling pressures ≥15 (for septal é) or > 12 (for lateral é) – elevated LV filling pressures	é Lateral values higher than septal ones *In patients with normal LVEF (≥50) has low sensitivity and high specificity. *In patients with mitral annular calcification, severe MR, or constrictive pericarditis might not give an adequate estimate of filling pressures. *Might not be valid for patients with acute decompensated heart failure
Pulmonary vein flow	S > D – normal S < D – elevated LA pressure or normal in young (<40) individuals	Influenced by age (D dominant in young individuals <40 years)
CO		
Doppler measurements using the LVOT VTI and LVOT diameter (2R)	$SV = \pi \times R^2 \times (LVOT\ VTI)$; $CO = SV \times HR$	LVOT VTI normal values: 18-20 cm; <12 cm suggestive of shock. Significant aortic regurgitation can lead to overestimation of the SV and consequently CO In the absence of pulmonic shunting the RVOT and RVOT VTI can be used as an alternate

IVCCI indicates IVC collapsibility index; HR, heart rate; LVEF, LV ejection fraction; MR, mitral regurgitation.