Assessment of the Right Ventricle and Inferior Vena Cava

Matthew Griffee, MD
Assistant Professor
University of Utah Department of Anesthesiology
Salt Lake City, Utah
Goals
Goals

- Review estimation of CVP from the IVC
Goals

• Review estimation of CVP from the IVC

• Review risk factors for RV dysfunction
Goals

• Review estimation of CVP from the IVC
• Review risk factors for RV dysfunction
• Review basic RV anatomy and physiology
Goals

- Review estimation of CVP from the IVC
- Review risk factors for RV dysfunction
- Review basic RV anatomy and physiology
- Learn how to assess RV systolic function
It is important to estimate CVP accurately because the echo based technique of estimating PA systolic pressure starts with CVP.
It is important to estimate CVP accurately because the echo based technique of estimating PA systolic pressure starts with CVP.
**RIGHT ATRIAL PRESSURE (CVP)**

**Inferior vena cava size and collapsibility:**

- Most common technique for CVP estimation
- IVC should be visualized in subcostal view
- Patient position: supine
  - IVC size is significantly larger in right lateral position
  - IVC size is significantly smaller in left lateral position
  
  Nakao, Am J Cardiol 1987;59:125-32

- IVC measurements
  - Just proximal to junction of hepatic veins (2cm from RA)
  - End-expiration and end-diastole & at end-inspiration or during a “sniff” maneuver
  
  Rudski JASE 2010; 23: 685-713

Important to emphasize that the IVC is used here for estimation of right sided pressure and NOT for estimation of “fluid status”.
RIGHT ATRIAL PRESSURE (CVP)

**Inferior vena cava size and collapsibility:**
- IVC collapsibility: the decrease of IVC diameter with inspiration (or the sniff maneuver)

Important to emphasize the limitations -- may not be accurate in all patients....
Inferior vena cava size and collapsibility:

- IVC collapsibility: the decrease of IVC diameter with inspiration (or the sniff maneuver)

Important to emphasize the limitations -- may not be accurate in all patients....
RIGHT ATRIAL PRESSURE (CVP)

**Inferior vena cava size and collapsibility:**

- IVC collapsibility: the decrease of IVC diameter with inspiration (or the sniff maneuver)

- IVC dilated > 2 cm in young people despite normal RAPs

  Nakao, Am J Cardiol 1987;59:125-32
  Simpson, J Am Coll Cardiol 1988;11:557-64

Important to emphasize the limitations -- may not be accurate in all patients....
**RIGHT ATRIAL PRESSURE (CVP)**

**Inferior vena cava size and collapsibility:**

- IVC collapsibility: the decrease of IVC diameter with inspiration (or the sniff maneuver)

**CAUTION**

- IVC dilated > 2 cm in young people despite normal RAPs


- IVC size should be cautiously evaluated in patients on mechanical ventilation


Important to emphasize the limitations -- may not be accurate in all patients....
Several algorithms have been proposed to estimate RAP through a combination of IVC size and collapsibility, different authors describe slightly different cutoffs in predicting RAP levels, but all share the same concept; as the RAP increases the IVC size increases and its normal collapsibility with inspiration decreases.

Presented here is the algorithm reported in the American Society of Echocardiography’s guidelines (go over chart).

Caveat: Athletes have been shown to have dilated IVCs with normal collapsibility. Studies have found that the mean IVC diameter in athletes was 2.31 ± .46 compared with 1.14 ± 0.13 in aged-matched control subjects. The highest diameters were seen in highly trained swimmers.
Several algorithm have been proposed to estimate RAP through a combination of IVC size and collapsibility; different authors describe slightly different cutoffs in predicting RAP levels, but all share the same concept; as the RAP increases the IVC size increases and its normal collapsibility with inspiration decreases.

Presented here is the algorithm reported in the American Society of Echocardiography’s guidelines (go over chart).

Caveat: Athletes have been shown to have dilated IVCs with normal collapsibility. Studies have found that the mean IVC diameter in athletes was 2.31 ± .46 compared with 1.14 ± 0.13 in aged-matched control subjects. The highest diameters were seen in highly trained swimmers.
Exceptions, Limitations

Caveat:

• Spontaneous breathing only!

• Athletes: dilated IVC with collapsibility index

• Mean IVC diameter 2.31±.46 vs 1.14±0.13 in age-matched control subjects

• Highest diameters were seen in highly trained swimmers

While many use the IVC size and collapsibility as a predictor of RAP, it is important to understand that it may not be as simple as one may think; for example, this fairly recent study looking at the correlation between IVC size and collapsibility and RAP concluded that the traditional classification of RAP into 5-mmHg ranges based on IVC size and collapsibility performed poorly, and suggested a broader cutoff of 10 mmHg.
Right Atrial Pressure (CVP)

Perpendicular to long axis of IVC; Just proximal to hepatic vein; 0.5-3cm from RA

Rudski LG et al J Am Soc Echocardiogr 2010; 23: 685-713
Right Atrial Pressure (CVP)

Table 3: Estimation of RA pressure on the basis of IVC diameter and collapse

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal (0-4 [2 mm Hg)]</th>
<th>Intermediate (5-10 [5 mm Hg])</th>
<th>High (15 mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVC diameter</td>
<td>≥2.1 cm</td>
<td>≥2.1 cm</td>
<td>&gt;2.1 cm</td>
</tr>
<tr>
<td>Collapse with sniff</td>
<td>&gt;60%</td>
<td>&lt;50%</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>Secondary indices of elevated RA pressure</td>
<td>• Restriction filling</td>
<td>• Tricuspid E/E' &gt; 8</td>
<td>• Diastolic flow predominance in hepatic veins (systolic filling fraction &lt; 55%)</td>
</tr>
</tbody>
</table>

Ranges are provided for low and intermediate categories, but for simplicity, midrange values of 3 mm Hg for normal and 8 mm Hg for intermediate are suggested. Intermediate (8 mm Hg) RA pressures may be downgraded to normal (3 mm Hg) if no secondary indices of elevated RA pressure are present, upgraded to high if minimal collapse with sniff (>50%) and secondary indices of elevated RA pressure are present, or left at 8 mm Hg if uncertain.

IVC, inferior vena cava; RA, right atrial.

Goals

- Review estimation of CVP from the IVC
- **Review risks factors for RV dysfunction**
- Review basic RV anatomy and physiology
- Learn how to assess RV systolic function
RISK FACTORS FOR RV DYSFUNCTION

- PHTN
- L-to-R shunt
- LV failure
- Pulmonary embolism
- Acute lung injury
- RV infarction
  - 30% mortality if InfWallMI + RV infarct
  - RVH → ↑ risk for RV ischemia

Signs of RV Dysfunction

Echo markers correlated to mortality in both PHTN and RV failure:

- RV EF%
- RV dilatation
- Tricuspid annular velocity
- RV myocardial performance index (MPI)
- Tricuspid regurgitation (TR)
- Right atrial size
- RV doppler strain
Goals

• Review estimation of CVP from the IVC

• Review risks of RV dysfunction

• **Review basic RV anatomy and physiology**

• Learn how to assess RV systolic function
RV Physiology

Effects on RV systolic function

- Interventricular forces
- LV function
- Preload
- Coronary Perfusion
- Afterload
- Pericardial restraint

N Engl J Med. 1993 Apr 8;328(14):981-8

Note: RV tolerates volume overload better than increased afterload.
Diagram of the right ventricle demonstrating its 3 major chamber components; inflow tract, infundibulum (outflow tract), and apex.
RV Anatomy

Normal RV

Dilated RV

Images: combination of contrast ventriculogram and 3D echo reconstruction.

Note complex shape of RV compared to LV.

Dilated RV from severe pulmonary insufficiency from tetralogy of fallot repair.
Schematic showing normal human left (LV) and right ventricular (RV) pressure–volume relationships. Unlike the rectangular LV loop, the RV is more trapezoidal, with poorly defined isovolumic periods. Note the continued ejection from the RV during pressure decline (arrow), correlating with the hangout period described by Shaver et al.
Goals

• Review estimation of CVP from the IVC
• Review risks of RV dysfunction
• Review basic RV anatomy and physiology
• Learn how to assess RV systolic function
Complex anatomy/dimensions make RV challenging to evaluate structure and function. Therefore, thorough assessment of RV is recommended.
Complex anatomy/dimensions make RV challenging to evaluate structure and function. Therefore, thorough assessment of RV is recommended.
Complex anatomy/dimensions make RV challenging to evaluate structure and function. Therefore, thorough assessment of RV is recommended.
RV Evaluation Techniques

RV systolic function summary snapshot

RV>LV ...severe dilatation

Septal flattening indicates RV pressure or volume overloading

Complex anatomy/ dimensions make RV challenging to evaluate structure and function. Therefore, thorough assessment of RV is recommended.
RV Evaluation Techniques

RV systolic function summary snapshot

- RV > LV ... severe dilatation

- RV wall thickness > 0.5cm
  - Hypertrophy - adaptation to PH

- Septal flattening indicates RV pressure or volume overloading

Complex anatomy/ dimensions make RV challenging to evaluate structure and function. Therefore, thorough assessment of RV is recommended.
Right Ventricle Size - 4Ch

RVD1 (base) < 4.2 cm
RVD2 (mid) < 3.5 cm
RVD3 (long axis) < 8.6 cm

Normal RV

Rudski JASE 2010; 23:685-713

First sign of RV dysfunction is dilatation.

Very easy measures to remember and to visually assess by looking at the centimetric scale: measure (at end-diastole) if in doubt.
RV Size - Parasternal

RVOT >3.3cm dilated

Rudski JASE 2010; 23:685-713
Dilatation of the RV is also assessed by comparison with the LV, looking at the relation of their areas in a 4-ch view. Here an example of RV bigger than LV (severe RV dysfunction).
Dilatation of the RV is also assessed by comparison with the LV, looking at the relation of their areas in a 4ch view. Here an example of RV bigger than LV (severe RV dysfunction)
Dilatation of the RV is also assessed by comparison with the LV, looking at the relation of their areas in a 4ch view. Here an example of RV bigger than LV (severe RV dysfunction).
Right Ventricle Dilation

Dilation of the RV is also assessed by comparison with the LV, looking at the relation of their areas in a 4ch view. Here an example of RV bigger than LV (severe RV dysfunction).

<table>
<thead>
<tr>
<th>RVEDA / LVEDA</th>
<th>MODERATE dilatation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.6</td>
<td></td>
</tr>
<tr>
<td>&gt; 1</td>
<td>SEVERE dilatation</td>
</tr>
</tbody>
</table>
RV stroke volume decreases dramatically with even modest increase in afterload. RV dilates when afterload increases. LV is a pressure pump, well adapted to increasing afterload.

Figure 4. The response of the RV and LV to experimental increase in afterload. Reproduced from MacNee with permission from the publisher. Copyright © 1994, the American Thoracic Society.
Two-Dimensional

RV dilatation

RV dimension: both evaluated qualitatively + quantitatively.
Two-Dimensional

RV dilatation

RV dimension: both evaluated qualitatively & quantitatively.
Two-Dimensional Pulmonary Embolism

RV dilatation

RV dimension: both evaluated qualitatively + quantitatively.
In addition to assessment of RV dimension, visual assessment lies on judgment on RV free wall motion.
The free wall can be hypokinetic or akinetic as seen on the example in the 4-ch view on the upper right example.
It can also have focal injury as seen in the subcostal view seen on the left. This is example of apical RV infarct in this patient with LAD MI.
In addition to assessment of RV dimension, visual assessment lies on judgment on RV free wall motion.
The free wall can be hypokinetic or akinetic as seen on the example in the 4-ch view on the upper right example.
It can also have focal injury as seen in the subcostal view seen on the left. This is example of apical RV infarct in this patient with LAD MI.
In addition to assessment of RV dimension, visual assessment lies on judgment on RV free wall motion. The free wall can be hypokinetic or akinetic as seen on the example in the 4-ch view on the upper right example. It can also have focal injury as seen in the subcostal view seen on the left. This is example of apical RV infarct in this patient with LAD MI.
Qualitative evaluation of RV: normal vs. Hypokinesis vs akinetic.
Qualitative evaluation of RV: normal vs. Hypokinesis vs akinetic.
Qualitative evaluation of RV: normal vs. Hypokinesis vs akinetic.
RV Kinesis

RV free wall hypertrophy?
(nl <5mm)

How to measure:
• Diastole
• Endocardium only

Challenges:
• Foreshortening
• Epicardial fat
• Trabeculation
• Moderator band

RV infarction
RV Kinesis

**RV free wall hypertrophy?**
(nl <5mm)

**Challenges:**
- Foreshortening
- Epicardial fat
- Trabeculation
- Moderator band

**RV infarction**

**How to measure:**
- Diastole
- Endocardium only

---

© Winfocus' CRITICAL CARE ECHOCARDIOGRAPHY
Fractional Area Change (FAC\%) \[\text{FAC\%} = \frac{\text{Area}_{\text{end-diastole}} - \text{Area}_{\text{end-systole}}}{\text{Area}_{\text{end-diastole}}} \times 100\]

<35% abnormal

R FAC surrogate measure of RV EF\%.

Figure: RVFAC measured at end-diastole (A) and end-systole (B). Both images are optimized by decreasing the depth or using the zoom function. The RVFAC is calculated as \(\frac{(25\, \text{cm}^2 - 10\, \text{cm}^2)}{25\, \text{cm}^2} \times 100 = 60\%\) (normal). \(\text{RVA}_D\), RV area at end-diastole; \(\text{RVA}_S\), RV area at end-systole.
M-mode can be used in evaluating RV systolic function by measuring TAPSE.

With the M-mode cursor aligned through the anterior tricuspid annulus in the apical 4-chamber view, longitudinal displacement of the annulus toward the apex during systole can be recorded as seen in this example. As the RV starts to fail, its normal motion toward the apex during systole starts to decrease.
M-mode can be used in evaluating RV systolic function by measuring TAPSE.

With the M-mode cursor aligned through the anterior tricuspid annulus in the apical 4-chamber view, longitudinal displacement of the annulus toward the apex during systole can be recorded as seen in this example.

As the RV starts to fail its normal motion toward the apex during systole starts to decrease.
M-mode: tricuspid annular plane systolic excursion (TAPSE)

TAM > 15 mm = normal
TAM < 16 mm = abnl. Recently, poor TAPSE measure correlated with ~40% mortality in AMI compared to health subjects.

Figure. TAPSE obtained before optimization (A) and after optimization (B) in the same patient. By zooming in on the TV annulus, accuracy and measurements of TAPSE were improved. The red line follows the contour of the annulus during the cardiac cycle. TAPSE in B = 2.0 cm (normal).
M-mode: TAPSE

Limitation of TAPSE: note regionally of RV motion apex vs basal. TAPSE may not reflect global RV function.
Limitation of TAPSE: note regionally of RV motion apex vs basal. TAPSE may not reflect global RV function.
Limitation of TAPSE: note regionally of RV motion apex vs basal. TAPSE may not reflect global RV function.
Limitation of TAPSE: note regionally of RV motion apex vs basal. TAPSE may not reflect global RV function.
Limitation of TAPSE: note regionally of RV motion apex vs basal. TAPSE may not reflect global RV function.
The interventricular septum should be convex into the RV in the short axis throughout the cardiac cycle. Abnormal septal motion indicates RV pressure or volume overloading.

- Septal motion may indicate RV pathology
- P-SAX clips:
  - Upper right - RV hypertension / increased afterload implicated by flattening of the septum with “D”-shaped LV during systole
  - Bottom left - RV volume overload implicated by both flattened septum during diastole as well as systole with obvious RV dilatation.
Right Ventricle Septum

The interventricular septum should be convex into the RV in the short axis throughout the cardiac cycle.

Abnormal septal motion

Septal flattening indicates RV pressure or volume overloading

- Septal motion may indicate RV pathology
- P-SAX clips:
  - Upper right - RV hypertension / increased afterload implicated by flattening of the septum with "D"-shaped LV during systole
  - Bottom left - RV volume overload implicated by both flattened septum during diastole as well as systole with obvious RV dilatation.
Right Ventricle Septum

The interventricular septum should be convex into the RV in the short axis throughout the cardiac cycle.

Abnormal septal motion

- Septal flattening indicates RV pressure or volume overloading
  - P-SAX clips:
    - Upper right - RV hypertension / increased afterload implicated by flattening of the septum with "D"-shaped LV during systole
    - Bottom left - RV volume overload implicated by both flattened septum during diastole as well as systole with obvious RV dilatation.
Doppler Measurement of Pressure Gradients with Bernoulli’s Equation

- Bernoulli’s equation measures pressure difference (or gradient) between chambers

- Simplified Bernoulli’s equation: \( \Delta P (P_2-P_1) = 4(V_2^2-V_1^2) = 4(V_2)^2 \)

- \( \Delta P = 4(V_2)^2 \)

Bernoulli’s equation per se measures pressure difference (or gradient) between chambers and not absolute pressure within them.

The original Bernoulli’s equation (1) (Fig. 1) is expansive and incorporates the physical properties of convective acceleration, flow acceleration, and viscous friction. In practical clinical terms, the effect of flow acceleration and viscous friction is minimal, and therefore can be ignored.

Also, as the blood flows through a narrowed orifice, the proximal velocity (V1) is much smaller compared to the velocity downstream (V2). Because the equation involves the square of both velocities, V1 has little impact in most cases. Therefore the final modified Bernoulli’s equation is...

If there is one equation that you need to remember from this course is the modified Bernoulli’s equation of \( 4V^2 \).
Bernoulli’s equation measures pressure difference (or gradient) between chambers.

- Simplified Bernoulli’s equation: \( \Delta P (P_2-P_1) = 4(V_2^2-V_1^2) = 4(V_2)^2 \)
- \( \Delta P = 4(V_2)^2 \)

Doppler Measurement of Pressure Gradients with Bernoulli’s Equation

Bernoulli’s equation per se measures pressure difference (or gradient) between chambers and not absolute pressure within them.

The original Bernoulli’s equation (1) (Fig. 1) is expansive and incorporates the physical properties of convective acceleration, flow acceleration, and viscous friction in practical clinical terms, the effect of flow acceleration and viscous friction is minimal, and therefore can be ignored.

Also, as the blood flows through a narrowed orifice, the proximal velocity \( V_1 \) is much smaller compared to the velocity downstream \( V_2 \).

Because the equation involves the square of both velocities, \( V_1 \) has little impact in most cases. Therefore the final modified Bernoulli’s equation is...

If there is one equation that you need to remember from this course is the modified Bernoulli’s equation of \( 4V^2 \).
Systolic pulmonary artery pressure (sPAP)

- sPAP = RV systolic pressure
  - Absence of pulmonary valve stenosis
  - Absence of RV outflow tract obstruction

- RV systolic pressure = RAP + (RV-RA) pressure gradient

- RAP: just described (use CVP if available)

- RV-RA pressure gradient: Modified Bernoulli equation
  \[ \Delta P = 4 \times V^2 \]
  - V = max. tricuspid regurgitation velocity (TRv)

Systolic pulmonary artery pressure (sPAP) is considered equal to right ventricular (RV) systolic pressure in the absence of pulmonary valve stenosis or outflow tract obstruction. RV systolic pressure can be determined by addition of right atrial (RA) pressure (RAP) to the pressure gradient between the right chambers. Many methods can be used to estimate RAP (most accurately is just to measure it...), while the pressure gradient between the right chambers can be calculated using the modified Bernoulli equation: \( \Delta P = 4 \times V^2 \) where \( V \) is the tricuspid regurgitant velocity (TRv).
Systolic pulmonary artery pressure (sPAP)

- sPAP = RV systolic pressure
  - Absence of pulmonary valve stenosis
  - Absence of RV outflow tract obstruction

- RV systolic pressure = RAP + (RV-RA) pressure gradient

- RAP: just described (use CVP if available)

- RV-RA pressure gradient: Modified Bernoulli equation
  \[ \Delta P = 4 \times V^2 \]
  - \( V \) = max. tricuspid regurgitation velocity (TRv)

Systolic pulmonary artery pressure (sPAP) is considered equal to right ventricular (RV) systolic pressure in the absence of pulmonary valve stenosis or outflow tract obstruction.

RV systolic pressure can be determined by addition of right atrial (RA) pressure (RAP) to the pressure gradient between the right chambers.

Many methods can be used to estimate RAP (most accurately is just to measure it...), while the pressure gradient between the right chambers can be calculated using the modified Bernoulli equation: \( \Delta P = 4 \times V^2 \) where \( V \) is the tricuspid regurgitant velocity (TRv).
how to....

- Windows:
  - Apical 4-chamber view
  - Parasternal short axis (3-in-1) view
  - Subcostal (if you’re lucky…)
- Place cursor across tricuspid valve
- Press on continuous wave Doppler (CW)
- Move cursor slowly from side to side to look for highest jet possible
- Tips:
  - Try to align cursor at 0°
  - Can use color Doppler across TV; if you see a TR jet, try to “catch” it..
how to....
how to....
Systolic pulmonary artery pressure (sPAP)
Questions?