Swan Song: Echocardiography as a Pulmonary Artery Catheter?
The swan is **white** without spot, and it sings sweetly as it dies, that song ending its life...

Leonardo Da Vinci
Echophysiology: the transesophageal echo probe as a noninvasive Swan–Ganz catheter

Melanie Meersch, Christoph Schmidt, and Alexander Zarbock

Curr Opin Anesthesiol 2016, 29:36–45

Echo-Doppler Hemodynamics
An Important Management Tool for Today’s Heart Failure Care
Roy Beigel, MD; Bojan Cercek, MD, PhD; Robert J. Siegel, MD; Michele A. Hamilton, MD

Circulation. 2015;131:1031-1034.

Echocardiography in the use of noninvasive hemodynamic monitoring

Roy Beigel, MD, Bojan Cercek, MD, PhD, Reza Arsanjani, MD, Robert J. Siegel, MD*

The Heart Institute, Cedars Sinai Medical Center, Los Angeles, CA

Journal of Critical Care 29 (2014) 184.e1–184.e8
Echocardiography as a Noninvasive Swan-Ganz Catheter
Jae K. Oh

Circulation. 2005;111:3192-3194

Doppler Echocardiography in Advanced Systolic Heart Failure
A Noninvasive Alternative to Swan-Ganz Catheter

Pier Luigi Temporelli, MD; Francesco Scapellato, MD; Ermanno Eleuteri, MD; Alessandro Imparato, MD; Pantaleo Giannuzzi, MD

Temporelli, Circ Heart Fail. 2010;3:387-394
Temporelli, Circ Heart Fail. 2010;3:387-394

Right Atrial Pressure
Normal Range
Mean: 1–5 mm Hg

Pulmonary-Artery Pressure
Normal Range
Systolic: 15–30 mm Hg
Diastolic: 4–12 mm Hg
Mean: 9–19 mm Hg

Right Ventricular Pressure
Normal Range
Systolic: 15–30 mm Hg
Diastolic: 1–7 mm Hg

Pulmonary-Capillary Wedge Pressure
Normal Range
Mean: 4–12 mm Hg
Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: A Report from the American Society of Echocardiography

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal (0-5 [3] mm Hg)</th>
<th>Intermediate (5-10 [8] 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; 50%</td>
<td>&lt; 50%</td>
<td>&lt; 50%</td>
</tr>
<tr>
<td>Secondary indices of elevated RA pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Restrictive filling
- Tricuspid E/E’ > 6
- Diastolic flow predominance in hepatic veins (systolic filling fraction < 55%)

Ruddski, J Am Soc Echocardiogr 2010;23:685-713
Noninvasive Evaluation of Right Atrial Pressure

Roy Beigel, MD, Bojan Cercek, MD, PhD, Huai Luo, MD, PhD, and Robert J. Siegel, MD, Los Angeles, California

Table 3  Indices of elevated RAP

- Dilated IVC with diminished respiratory collapse
- Tricuspid E/e' ratio > 6
- Diastolic flow predominance in the SVC, jugular vein, or hepatic veins
- Bulging interatrial septum to the left atrium
- Dilated right atrium

J Am Soc Echocardiogr 2013;26:1033-42
Noninvasive Evaluation of Right Atrial Pressure

Roy Beigel, MD, Bojan Cercek, MD, PhD, Huai Luo, MD, PhD, and Robert J. Siegel, MD, Los Angeles, California

Table 4 Causes for IVC enlargement in the presence of normal RAP

- Prominent Eustachian valve
- Athletic training
- Large BSA
- Mechanical ventilation
- Narrowing of the IVC-RA junction
- Web or tissue present in the IVC

J Am Soc Echocardiogr 2013;26:1033-42
Estimation of Mean Right Atrial Pressure Using Tissue Doppler Imaging

Maged F. Nageh, MD, Helen A. Kopelen, RDMS, William A. Zoghbi, MD, Miguel A. Quiñones, MD, and Sherif F. Nagueh, MD

E/Ea > 6 = RAP >10 mmHg
Se 79% and Sp 73%

Nageh The american Journal of Cardiology, Vol 84; 1999
- Acceleration rate of E wave
- Rate > 560 cm/s² predicted a RAP > 5mmHg (Se 100% and Sp 99%)
- Independent predictor of RAP

Am Jour of Cardiology 1998
Noninvasive Estimation of Right Ventricular Filling Pressure by Ratio of Early Tricuspid Inflow to Annular Diastolic Velocity in Patients with and Without Recent Cardiac Surgery

Leyla Elif Sade, MD, Oyku Gulmez, MD, Serpil Eroglu, MD, Atilla Sezgin, MD,

\[ \text{RAP} = 1.62 \frac{E}{E'} + 2.13 \]

J Am Soc Echocardiogr 2007;20:982-988
Pressure Waveforms in the Right Heart and Pulmonary Artery.

**Right Atrial Pressure**
- Normal Range: Mean: 1–5 mm Hg

**Pulmonary-Artery Pressure**
- Normal Range:
  - Systolic: 15–30 mm Hg
  - Diastolic: 4–12 mm Hg
  - Mean: 9–19 mm Hg

**Right Ventricular Pressure**
- Normal Range:
  - Systolic: 15–30 mm Hg
  - Diastolic: 1–7 mm Hg

**Pulmonary-Capillary Wedge Pressure**
- Normal Range:
  - Mean: 4–12 mm Hg

DIAGNOSTIC METHODS
DOPPLER ECHOCARDIOGRAPHY

Noninvasive estimation of right ventricular systolic pressure by Doppler ultrasound in patients with tricuspid regurgitation

Paul G. Yock, M.D., and Richard L. Popp, M.D.

JVP + ΔP = RVSP

Circulation 70, No 4, 657-662, 1984
Yock, Circulation 70, No 4, 657-662, 1984
Apical 4 Chamber or RV modified RV inflow RV inflow/outflow

- Alignment with TR jet
- Estimation of RVSP. Continuous wave doppler
  - TR jet velocity in m/s
  - $RVSP = 4 \times (TR)^2 + RAP$
- Agitated saline
Table 3 Frequency of adequate Doppler signals in different transoesophageal echocardiographic views. Values are number (proportion).

<table>
<thead>
<tr>
<th>View</th>
<th>Pre-operative (n = 109)</th>
<th>Postoperative (n = 103)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four-chamber view</td>
<td>9 (9%)</td>
<td>6 (6%)</td>
<td>0.688</td>
</tr>
<tr>
<td>RV inflow–outflow view</td>
<td>45 (41%)</td>
<td>39 (38%)</td>
<td>0.377</td>
</tr>
<tr>
<td>Modified bicaval view</td>
<td>50 (46%)</td>
<td>42 (41%)</td>
<td>0.618</td>
</tr>
<tr>
<td>Any view</td>
<td>64 (59%)</td>
<td>54 (52%)</td>
<td>0.296</td>
</tr>
</tbody>
</table>

RV, right ventricular.
Echocardiographic Doppler Estimation of Pulmonary Artery Pressure in Critically Ill Patients with Severe Hypoxemia

Bélaïd Bouhemad, M.D.,* Fabio Ferrari, M.D., Ph.D.,† Kris Leleu, M.D.,‡ Charlotte Arbelot, M.D.,§ Qin Lu, M.D., Ph.D.,‖ Jean-Jacques Rouby, M.D., Ph.D.#

\[ Y = 6.9 + 0.8X \]
\[ r = 0.73; p < 0.001 \]

Anesthesiology, V 108, No 1, Jan 2008
The utility of transoesophageal echocardiography for estimating right ventricular systolic pressure

B. Cowie,¹,² R. Kluger,¹ S. Rex² and C. Missant³
Doppler under Pressure: It’s Time to Cease the Folly of Chasing the Peak Right Ventricular Systolic Pressure

Nelson B. Schiller, MD, and Bryan Ristow, MD, San Francisco, California

Schiller, JASE 2013
Table 1—Partial List of Potential Pitfalls Associated With Inaccurate DE Estimates of sPAP

<table>
<thead>
<tr>
<th>DE Pitfall</th>
<th>DE Underestimation of sPAP</th>
<th>DE Overestimation of sPAP</th>
<th>DE Underestimation or Overestimation of sPAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler beam not parallel with the TR jet</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of severe TR</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure measurements not made at end expiration</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiscriminate use of the highest measured TR velocity (i.e., in presence of arrhythmias)</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of pulmonic stenosis</td>
<td></td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Excessive Doppler gain</td>
<td></td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>“Guesstimate” of right atrial pressure (echocardiographically or clinically)</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dependence on the modified Bernoulli equation</td>
<td>***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of TR</td>
<td></td>
<td></td>
<td>*sPAP estimation not possible with DE</td>
</tr>
</tbody>
</table>

DE = Doppler echocardiography; sPAP = systolic pulmonary artery pressure; TR = tricuspid regurgitation.
Diagnostic accuracy of echocardiography for pulmonary hypertension: a systematic review and meta-analysis

Surinder Janda, Neal Shahidi, Kenneth Gin, John Swiston

R = 0.7 (95% CI: 0.65-0.77)

Heart 2011;97:612e622.

**Right Atrial Pressure**
- Normal Range: Mean: 1–5 mm Hg

**Right Ventricular Pressure**
- Normal Range:
  - Systolic: 15–30 mm Hg
  - Diastolic: 1–7 mm Hg

**Pulmonary-Artery Pressure**
- Normal Range:
  - Systolic: 15–30 mm Hg
  - Diastolic: 4–12 mm Hg
  - Mean: 9–19 mm Hg

**Pulmonary-Capillary Wedge Pressure**
- Normal Range:
  - Mean: 4–12 mm Hg
In absence of
- RVOT obstruction
- PV stenosis
- VSD

RVSP = PA systolic pressure
Figure 6. Doppler examination of the pulmonary artery blood flow velocity in a patient with acute respiratory distress syndrome.
Evaluation of Pulmonary Artery Pressure and Resistance by Pulsed Doppler Echocardiography

Ali Dabestani, MD, Gregory Mahan, MD, Julius M. Gardin, MD, Katsu Takenaka, MD, Cora Burn, RN, Alice Allfie,

Acceleration time

Mean PA pressure = 79 – (0.45x AT)

if At < 120 ms → 90 (0.62 x AT)

Dabestani, Am J Cardiol 1987: 59 662-668
Mean PAP = 4 (early PI vel)$^2$ + RAP

Diastolic PAP = 4 (end PI vel)$^2$ + RAP

Mean PA = $\frac{1}{3}$ systolic PA pressure + $\frac{2}{3}$ diastolic PA pressure

Rudski, JASE 2010: 23: 685-713

- **Right Atrial Pressure**
  - Normal Range
  - Mean: 1–5 mm Hg

- **Pulmonary-Artery Pressure**
  - Normal Range
  - Systolic: 15–30 mm Hg
  - Diastolic: 4–12 mm Hg
  - Mean: 9–19 mm Hg

- **Right Ventricular Pressure**
  - Normal Range
  - Systolic: 15–30 mm Hg
  - Diastolic: 1–7 mm Hg

- **Pulmonary-Capillary Wedge Pressure**
  - Normal Range
  - Mean: 4–12 mm Hg
Clinical Utility of Doppler Echocardiography and Tissue Doppler Imaging in the Estimation of Left Ventricular Filling Pressures

A Comparative Simultaneous Doppler-Catheterization Study

S.R. Ommen, MD; R.A. Nishimura, MD; C.P. Appleton, MD; F.A. Miller, MD; J.K. Oh, MD; M.M. Redfield, MD; A.J. Tajik, MD

Circulation, 2000; 102:1788-1794

MV E/e’ 2.82
Clinical Utility of Doppler Echocardiography and Tissue Doppler Imaging in the Estimation of Left Ventricular Filling Pressures

A Comparative Simultaneous Doppler-Catheterization Study

S.R. Ommen, MD; R.A. Nishimura, MD; C.P. Appleton, MD; F.A. Miller, MD; J.K. Oh, MD; M.M. Redfield, MD; A.J. Tajik, MD

Ommen, Circulation, 2000; 102:1788-1794
Doppler Tissue Imaging: A Noninvasive Technique for Evaluation of Left Ventricular Relaxation and Estimation of Filling Pressures

SHERIF F. NAGUEH, MD, KATHERINE J. MIDDLETON, RCT, HELEN A. KOPELEN, RDMS,

\[ Y = 1.9 + 1.24 \times X \]

\[ R = 0.87 \]

\[ N = 60 \]

Mean PCWP = 1.91 + (1.24 E/Ea)

J Am Coll Cardiol 1997;30:1527–33
1. Not accurate in
   1. Normal subjects (load dependency)
   2. Heavy annular calcification
   3. Mitral valve disease
   4. Pericardial disease

2. “Gray zone” of values

3. Reduced accuracy in patients with CAD and regional dysfunction

4. Different cutoff values depending on the site used


Pressure Waveforms in the Right Heart and Pulmonary Artery.

**Right Atrial Pressure**
- Normal Range: 1–5 mm Hg

**Pulmonary-Artery Pressure**
- Normal Range: Systolic: 15–30 mm Hg, Diastolic: 4–12 mm Hg, Mean: 9–19 mm Hg

**Right Ventricular Pressure**
- Normal Range: Systolic: 15–30 mm Hg, Diastolic: 1–7 mm Hg

**Pulmonary-Capillary Wedge Pressure**
- Normal Range: Mean: 4–12 mm Hg
Combined Doppler and Phased-array Echocardiographic Estimation of Cardiac Output

Paul A. Magnin, B.S.E., James A. Stewart, M.D., Sondra Myers, R.D.M.S.,
Olaf von Ramm, Ph.D., and Joseph A. Kisslo, M.D.


Pulsed Doppler echocardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window

Jannet F. Lewis, M.D., Lawrence C. Kuo, M.D., Jean G. Nelson, R.D.M.S.,
Marian C. Limacher, M.D., and Miguel A. Quinones, M.D.

Circulation 1984; 70: 425-431
CO = LVOT CSA x LVOT VTI x HR

Stroke Volume

Circulation 70, No. 3, 425-431, 1984
\[ CO = LVOT\ CSA \times LVOT\ VTI \times HR \]

- (Error)\(^2\)
- Appropriate VTI
- Alignement
- Distance from the valve
Other Parameters…

- Pulmonary vascular resistance
- Systemic vascular resistance
- LA pressure from Mitral Regurgitation
- LVEDP from Aortic Regurgitation
Usefulness of Noninvasive Assessment of Aortic Stenosis Before and After Percutaneous Aortic Valvuloplasty

$R = 0.42$

Come, Am J Cardiol 1988; 61:1300-1306
Laënnec 1816, France
The Importance of Knowing the Right Question

The Only Thing I Truly Know...

Is That I Know Nothing

- Socrates

Public domain
Merci de votre attention...