Echocardiography

PA Catheter in a Box

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Mayo Clinic, Arizona

mayo

DISCLOSURE

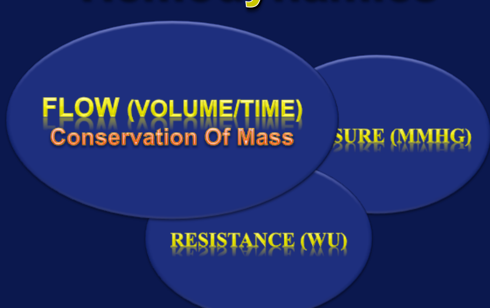
<u>Relevant Financial Relationship(s)</u>

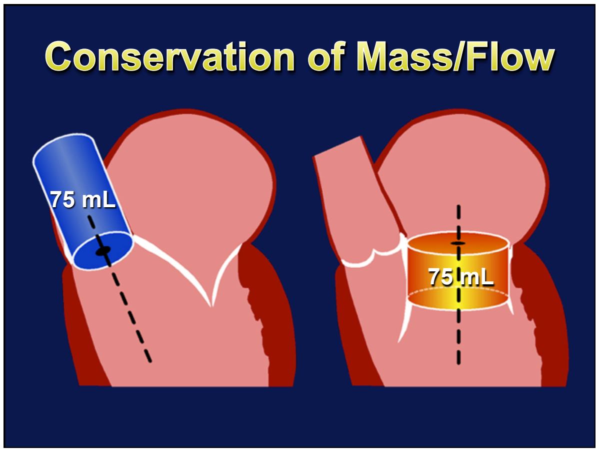
None

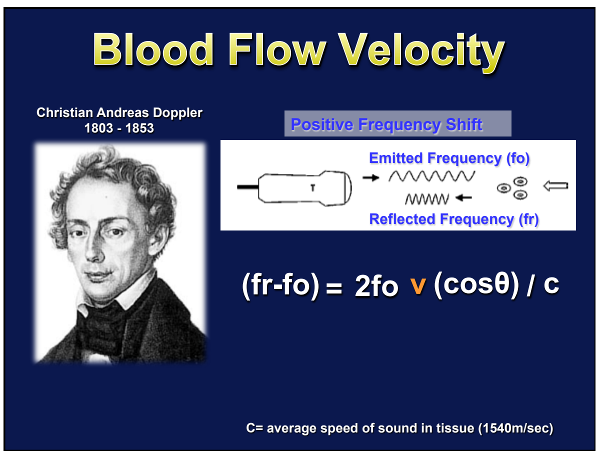
<u>Off Label Usage</u>

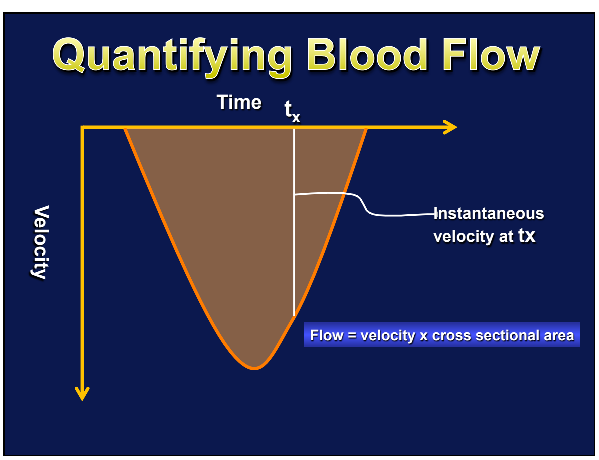
None

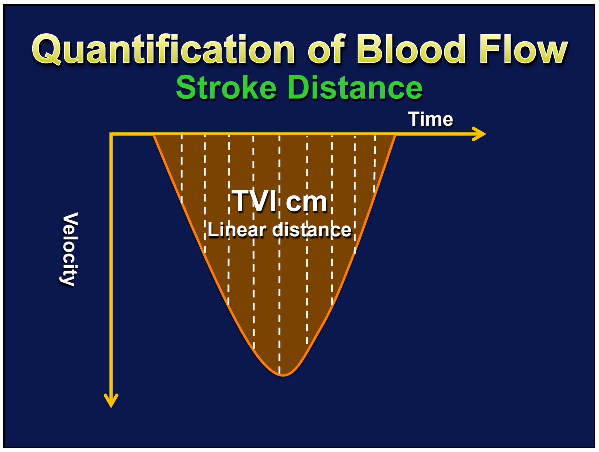
Hemodynamics

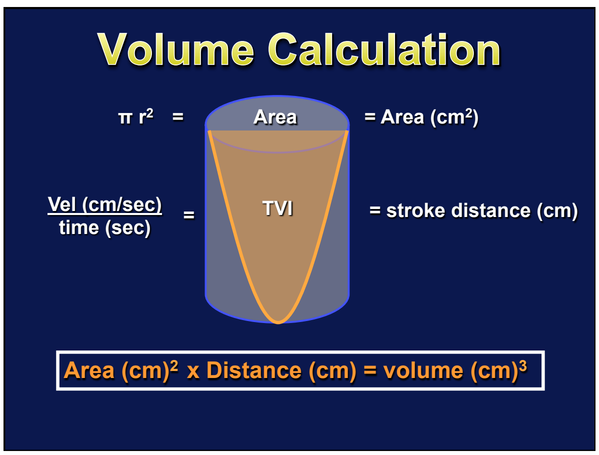


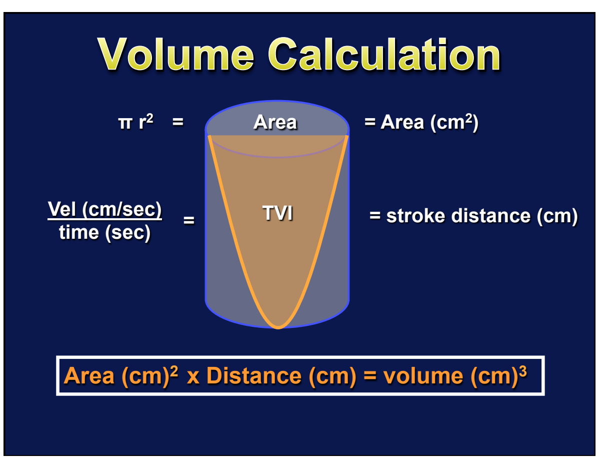

Conservation of Mass/Flow
75 mL
75 mL


Blood Flow Velocity
Christian Andreas Doppler
1803 - 1853
Positive Frequency Shift
Emitted Frequency (fo)
Reflected Frequency (fr)
(fr-fo) = 2fo v (cosθ) / c
C= average speed of sound in tissue (1540m/sec)

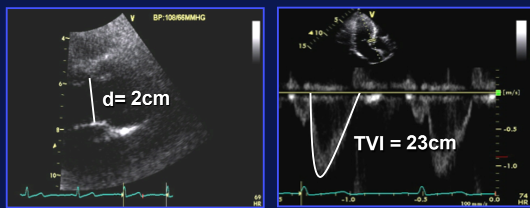

Quantifying Blood Flow
Time
tx
Velocity
Instantaneous velocity at tx
Flow = velocity x cross sectional area


Quantification of Blood Flow
Stroke Distance
Time
Velocity
TVI cm
Linear distance


Volume Calculation
π r2 =
Area
= Area (cm2)
Vel (cm/sec)
time (sec)
=
TVI
= stroke distance (cm)
Area (cm)2 x Distance (cm) = volume (cm)3

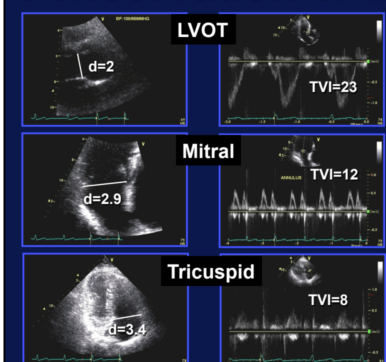

Volume Calculation
π r2 =
Area
= Area (cm2)
Vel (cm/sec)
time (sec)
=
TVI
= stroke distance (cm)
Area (cm)2 x Distance (cm) = volume (cm)3

Stroke Volume



Stroke Volume = CSA x TVI
= .785 (   )^2 x
= 72 cm^3 or ml

Conservation of Mass/Flow

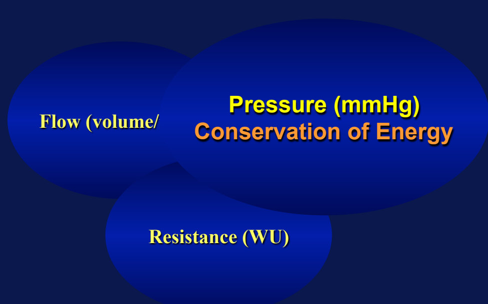


SV = 72cc

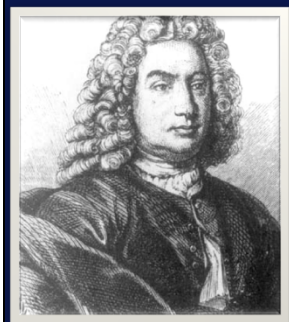
SV = 79cc

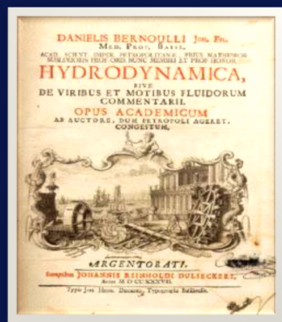
SV = 72cc

Hemodynamics



Daniel Bernoulli
1700-1782





Bernoulli Equation

P1-P2 = $\mathbf{1/2\rho(V_2^2 - V_1^2)}$ *Convective acceleration*

\+

$\rho \int (dv/dt) * ds$ *Flow acceleration*

\+

$R(\mu)$ *Viscous Friction*

P1&V1= proximal to obstruction
P2&V2= distal to obstruction
ρ=mass density of blood
R=viscous resistance
μ = viscosity

Bernoulli Equation

ΔP = $\mathbf{1/2\rho(V_2^2 - V_1^2)}$ *Convective acceleration*

\+

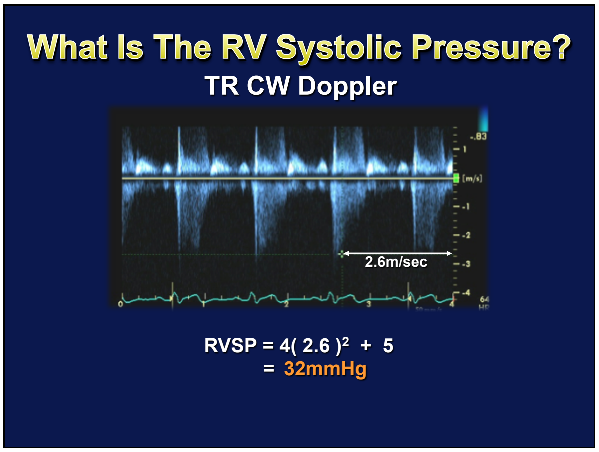
$\rho \int (dv/dt) * ds$ *Flow acceleration*

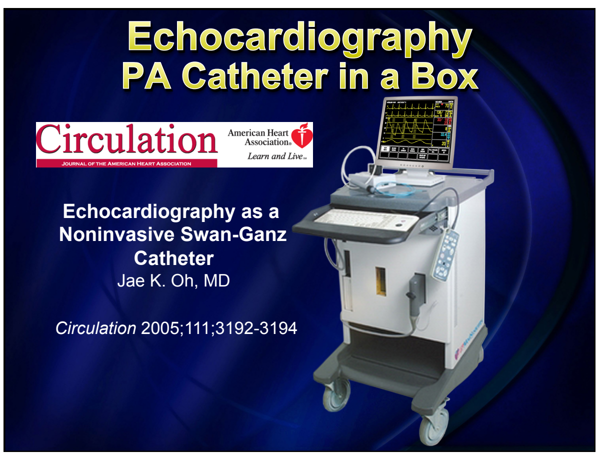
\+

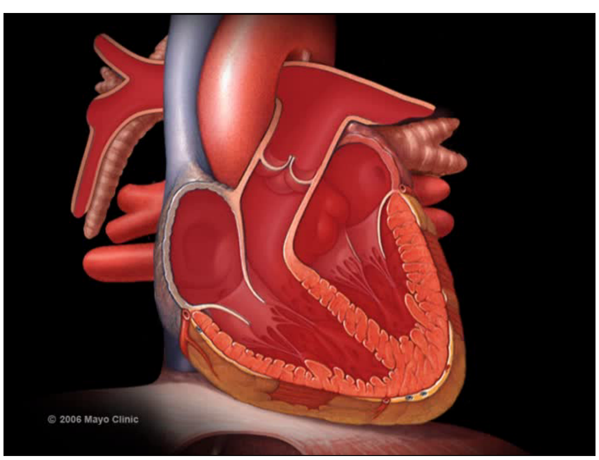
$R(\mu)$ *Viscous Friction*

V_1 <<< V_2 therefore ignore V_1

$$\Delta P = 4V_2^2$$


What Is The RV Systolic Pressure?
TR CW Doppler
2.6m/sec
RVSP = 4(2.6)² + 5
= 32mmHg


Echocardiography
PA Catheter in a Box
Circulation
American Heart Association
Learn and Live
Echocardiography as a Noninvasive Swan-Ganz Catheter
Jae K. Oh, MD
Circulation 2005;111;3192-3194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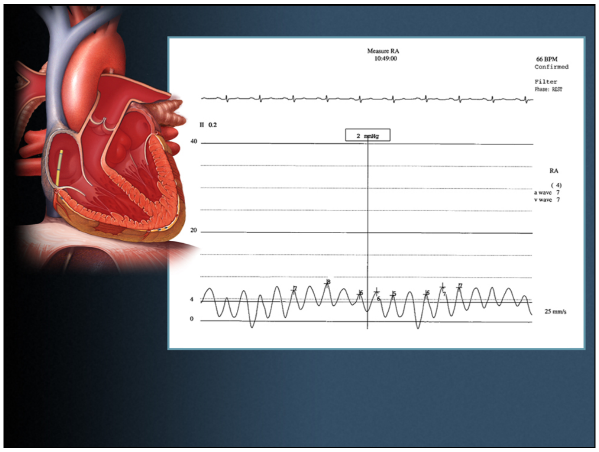
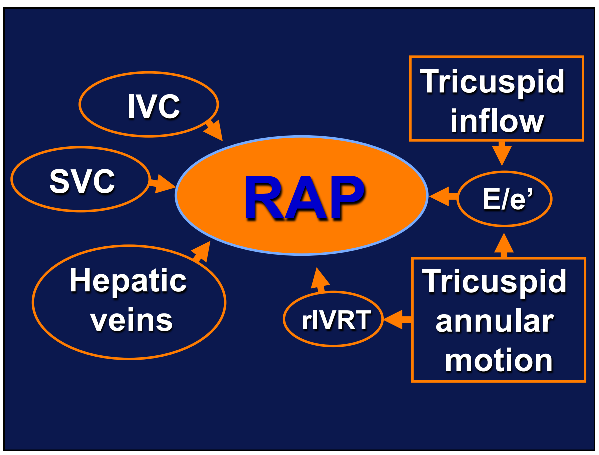
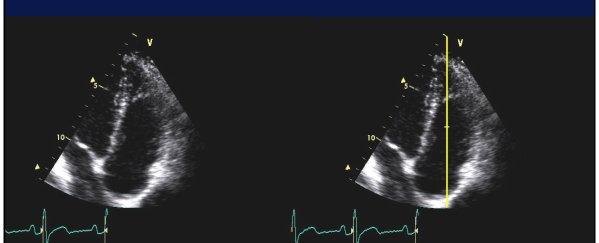
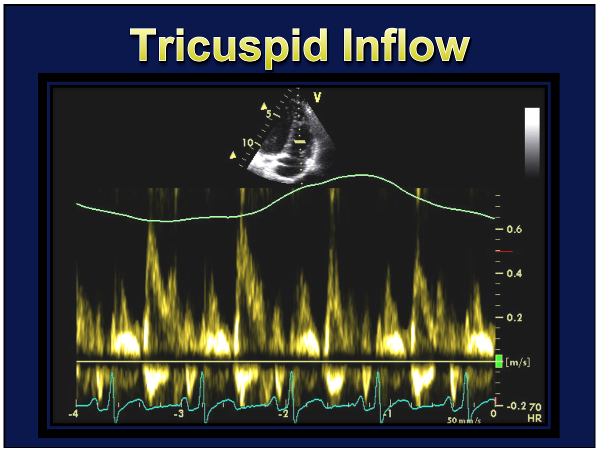
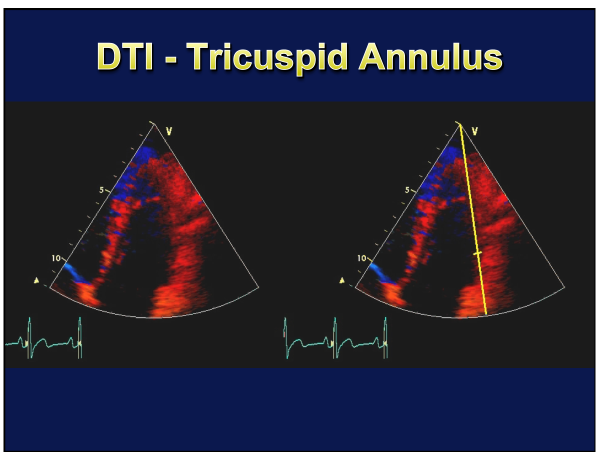


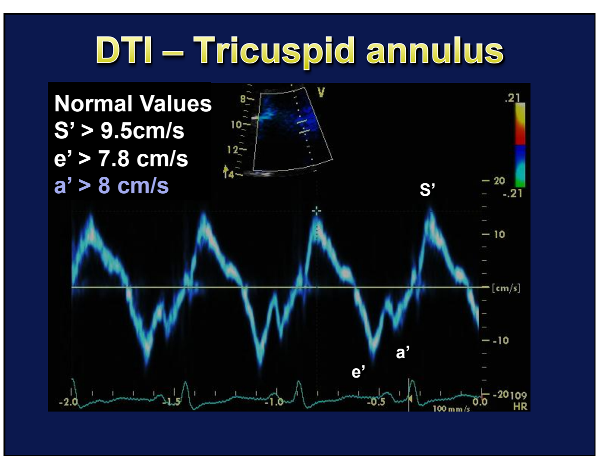


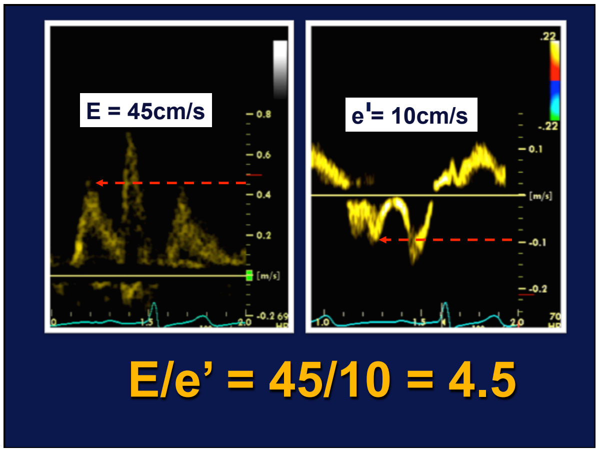
Tricuspid Inflow

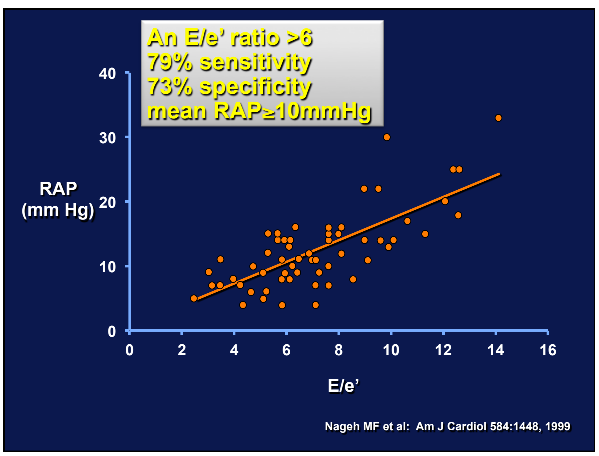


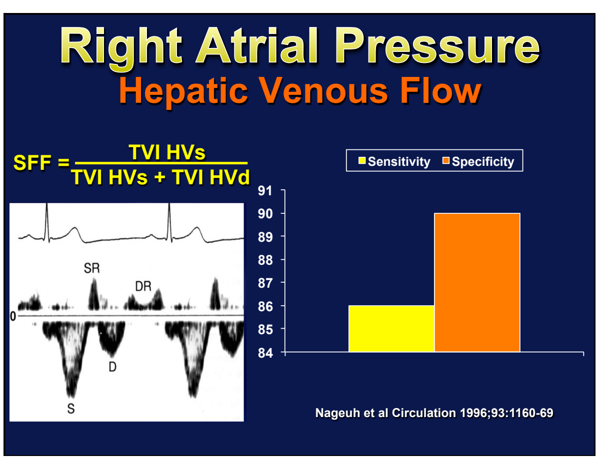

Tricuspid Inflow


DTI - Tricuspid Annulus

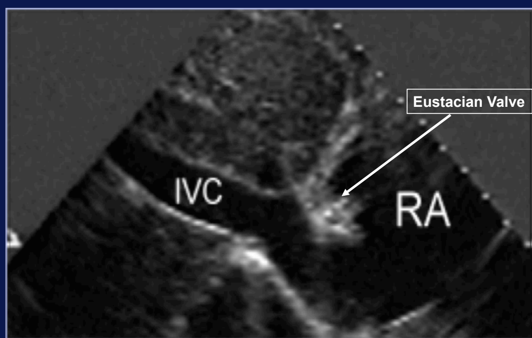

DTI – Tricuspid annulus
Normal Values
S’ > 9.5cm/s
e’ > 7.8 cm/s
a’ > 8 cm/s
S’
a’
e’


E = 45cm/s
e' = 10cm/s
E/e' = 45/10 = 4.5

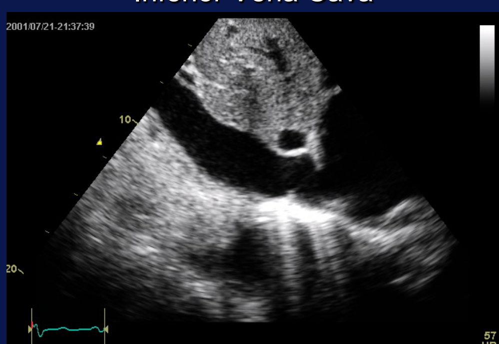

An E/e' ratio >6
79% sensitivity
73% specificity
mean RAP≥10mmHg
RAP (mm Hg)
E/e'
Nageh MF et al: Am J Cardiol 584:1448, 1999


Right Atrial Pressure
Hepatic Venous Flow
SFF = TVI HVs / TVI HVs + TVI HVd
Sensitivity
Specificity
SR
DR
D
S
Nageuh et al Circulation 1996;93:1160-69

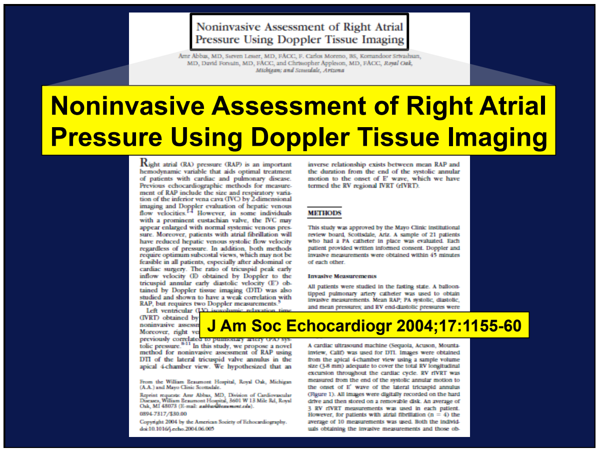
Right Atrial Pressure
Inferior Vena Cava

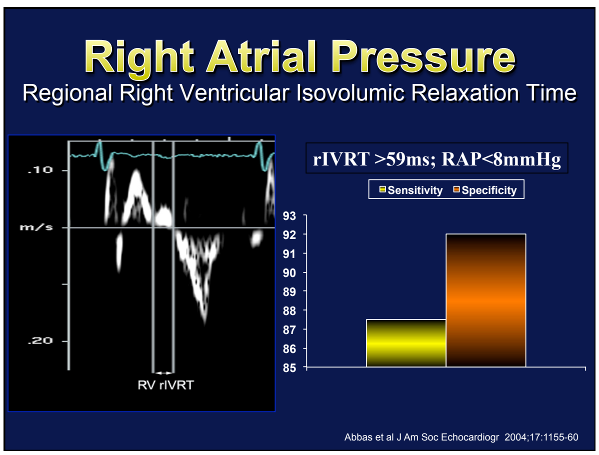


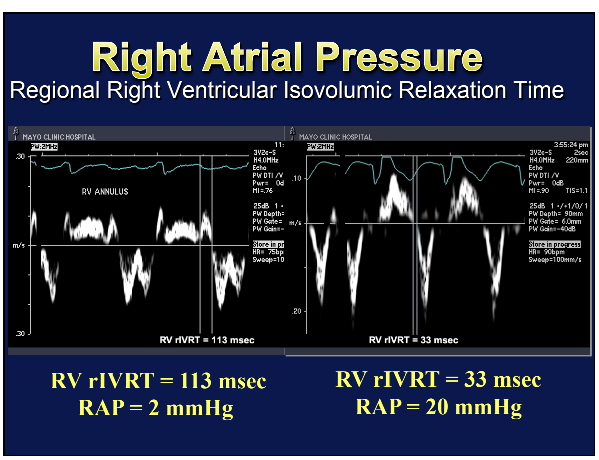
Right Atrial Pressure
Inferior Vena Cava

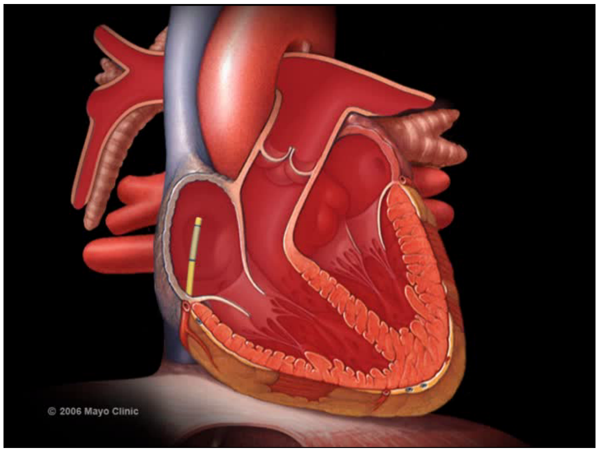


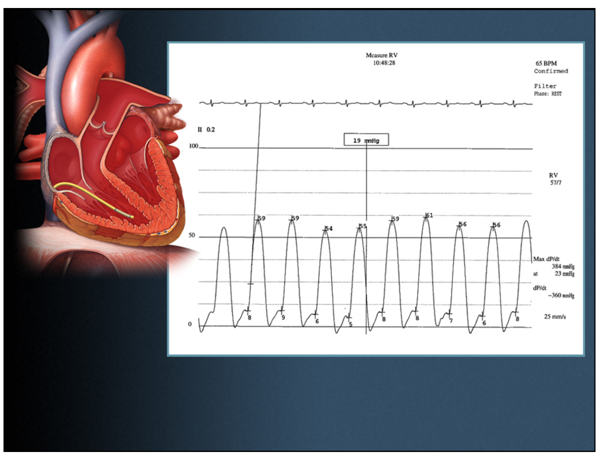
"IVC > 12mm had no predictive value for right atrial pressure"
Jue et al J Am Soc Echocardiogr 1992;5:613-19

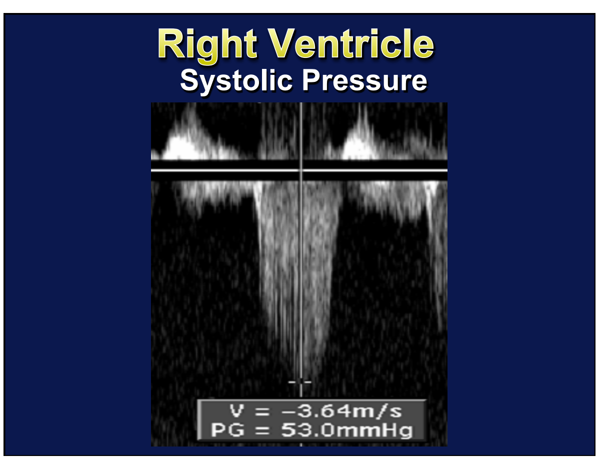

Noninvasive Assessment of Right Atrial Pressure Using Doppler Tissue Imaging
Noninvasive Assessment of Right Atrial Pressure Using Doppler Tissue Imaging
J Am Soc Echocardiogr 2004;17:1155-60

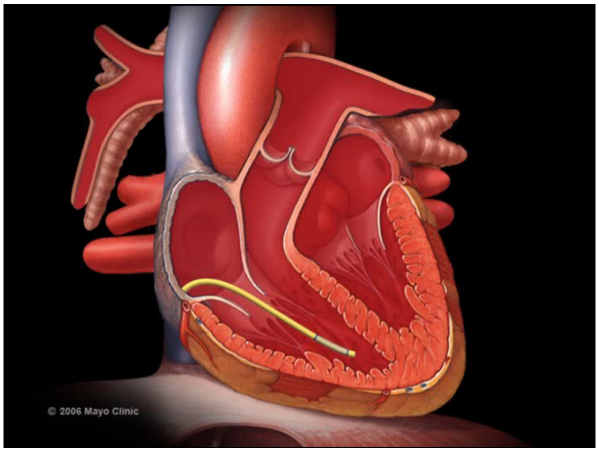

Right Atrial Pressure
Regional Right Ventricular Isovolumic Relaxation Time
.10
m/s
.20
RV rIVRT
rIVRT >59ms; RAP<8mmHg
Sensitivity
Specificity
93
92
91
90
89
88
87
86
85
Abbas et al J Am Soc Echocardiogr 2004;17:1155-60


Right Atrial Pressure
Regional Right Ventricular Isovolumic Relaxation Time
MAYO CLINIC HOSPITAL
RV ANNULUS
RV rIVRT = 113 msec
RV rIVRT = 33 msec
RV rIVRT = 113 msec
RAP = 2 mmHg
RV rIVRT = 33 msec
RAP = 20 mmHg


© 2006 Mayo Clinic


Measure RV
10:48:28
65 BPM
Confirmed
Filter
Phase: REST
II 0.2
19 mmHg
100
50
0
RV
57/7
Max dP/dt
384 mmHg
at 23 mmHg
dP/dt
-360 mmHg
25 mm/s


Right Ventricle
Systolic Pressure
V = -3.64m/s
PG = 53.0mmHg



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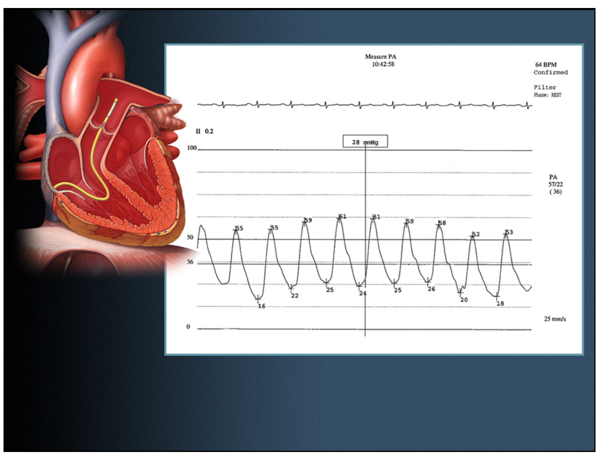
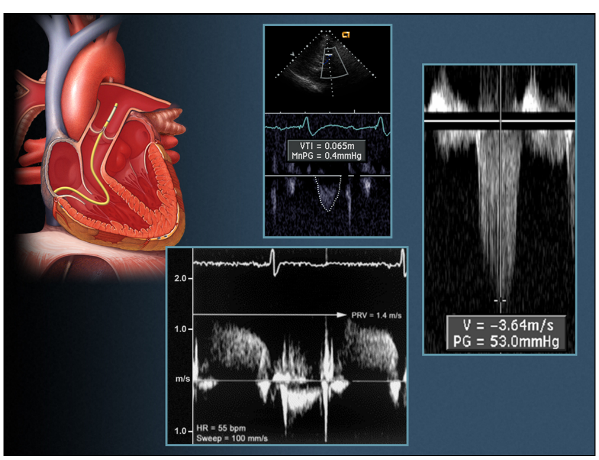


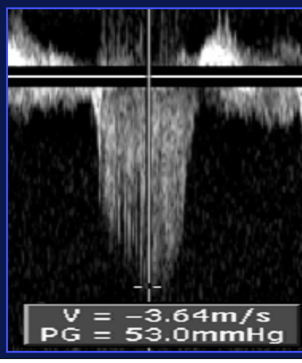
Measure PA
10:42:58
64 BPM
Confirmed
Filter
Phase: REST
II 0.2
28 mmHg
100
50
36
0
PA
57/22
(36)
25 mm/s



VTI = 0.065m
MnPG = 0.4mmHg
2.0
1.0
m/s
1.0
PRV = 1.4 m/s
HR = 55 bpm
Sweep = 100 mm/s
V = -3.64m/s
PG = 53.0mmHg

Pulmonary Artery

Systolic Pressure**



Estimate of RVSP / PASP

Assumptions

1. Velocity is only dependent on pressure.

$(fr\text{-}fo) = 2fo\ v\ (\cos\theta) / c$

Doppler Frequency Shift Equation

- If V1 is significant (>1.5 m/sec)
- Presence of anemia (viscous friction)

Estimate of RVSP / PASP

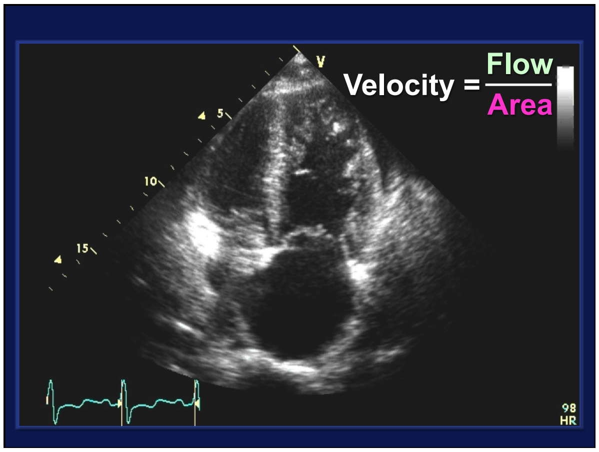
Assumptions

1. Velocity is only dependent on pressure.

Flow = Area x Velocity

Heart Rate

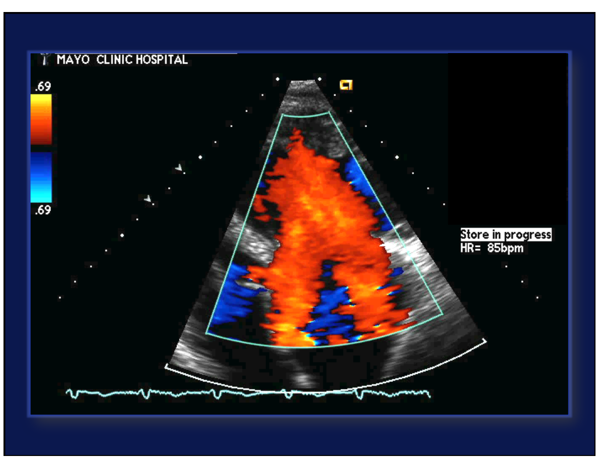
Contractility



Estimate of RVSP / PASP

Assumptions

1. Velocity is only dependent on pressure.
2. You can accurately estimate right atrial pressure.
   - Non simultaneous
   - Peak systole



Estimate of RVSP / PASP
Assumptions

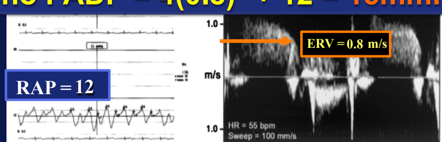
1. Velocity is only dependent on pressure.
2. You can accurately estimate right atrial pressure.
3. Right ventricular systolic pressure = Pulmonary artery systolic pressure

Pulmonary Artery
Diastolic Pressure

Pulmonary Pressure = 33 / 16

Cath PADP = 16mmHg

Echo PADP = $4(0.8)^2 + 12$ = 15mmHg



Echocardiographic Determination of Mean Pulmonary Artery Pressure

Amr E. Abbas, MD, F. David Fortuin, MD, Nelson B. Schiller, MD, Christopher P. Appleton, MD, Carlos A. Moreno, BS, and Steven J. Lester, MD

Echocardiographic Determination of Mean Pulmonary Artery Pressure

Am J Cardiol 2003;92:1373-1376

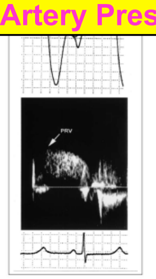
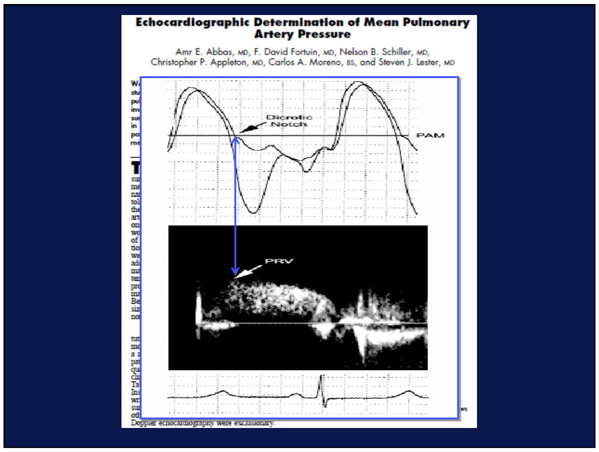
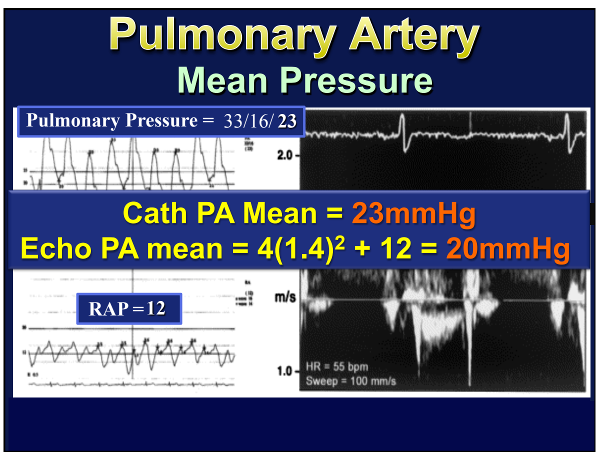
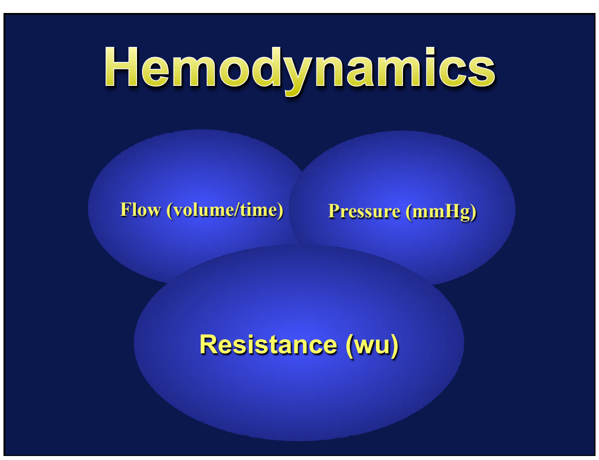


FIGURE 1. Occurrence of PRV close to the dicrotic notch allows for its use in determining mean PA pressure (PAM).

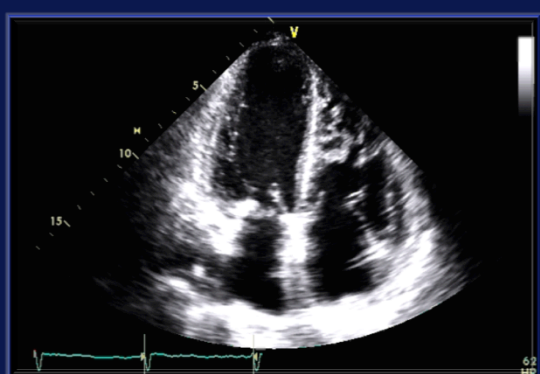

Echocardiographic Determination of Mean Pulmonary Artery Pressure
Amr E. Abbas, MD, F. David Fortuin, MD, Nelson B. Schiller, MD,
Christopher P. Appleton, MD, Carlos A. Moreno, BS, and Steven J. Lester, MD
Dicrotic Notch
PAM
PRV

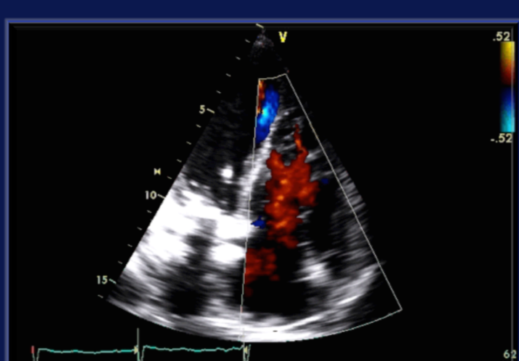

Pulmonary Artery
Mean Pressure
Pulmonary Pressure = 33/16/23
2.0
Cath PA Mean = 23mmHg
Echo PA mean = 4(1.4)² + 12 = 20mmHg
RAP = 12
m/s
1.0
HR = 55 bpm
Sweep = 100 mm/s


Hemodynamics
Flow (volume/time)
Pressure (mmHg)
Resistance (wu)

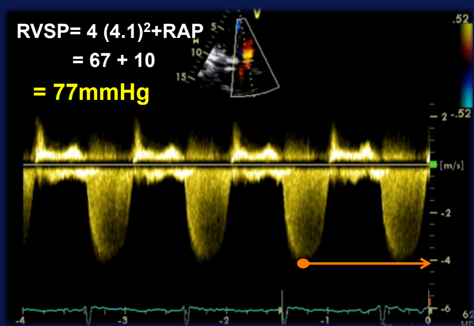
Case

- 65 y/o women
- Chronic kidney disease status post renal transplant.
- Left arm AV fistula
- Cirrhosis felt secondary to alcohol abuse and NASH



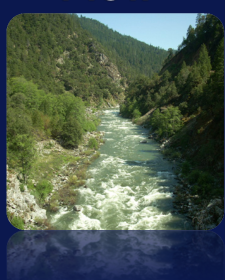


Right Ventricular Systolic Pressure



Pressure is the Product of

Flow x **Resistance**

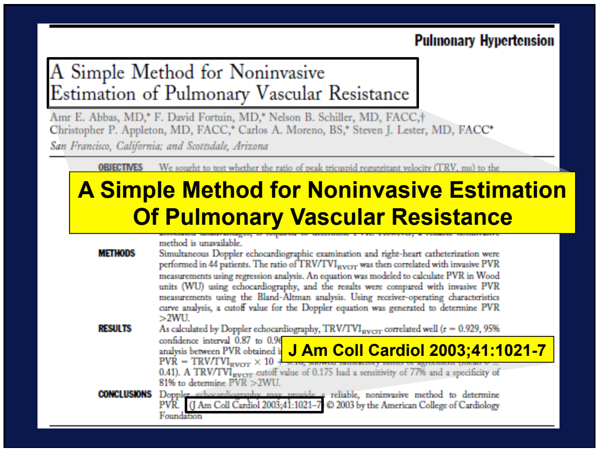


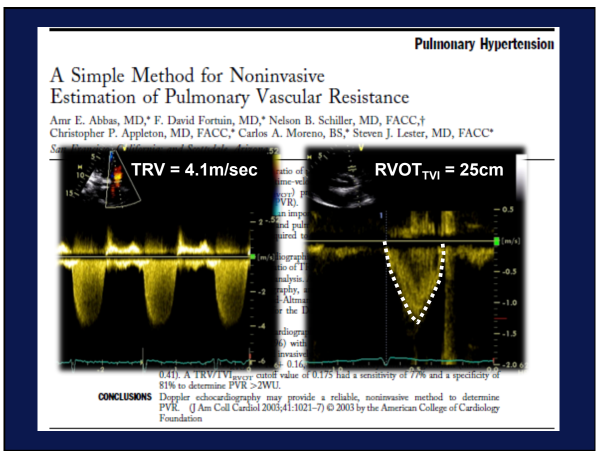
Calculation of Pulmonary Vascular Resistance

PVR = $\frac{\text{Transpulmonary pressure } (\Delta p)}{\text{Transpulmonary flow (Qp)}}$

= $\frac{\text{PAM} - \text{PCWP}}{\text{CO}}$

PAM = Mean pulmonary artery pressure
PCWP = Mean pulmonary capillary wedge pressure
CO = Cardiac output


Pulmonary Hypertension
A Simple Method for Noninvasive Estimation of Pulmonary Vascular Resistance
Amr E. Abbas, MD,* F. David Fortuin, MD,* Nelson B. Schiller, MD, FACC,† Christopher P. Appleton, MD, FACC,* Carlos A. Moreno, BS,* Steven J. Lester, MD, FACC*
San Francisco, California; and Scottsdale, Arizona
A Simple Method for Noninvasive Estimation Of Pulmonary Vascular Resistance
METHODS
Simultaneous Doppler echocardiographic examination and right-heart catheterization were performed in 44 patients. The ratio of TRV/TVIRVOT was then correlated with invasive PVR measurements using regression analysis. An equation was modeled to calculate PVR in Wood units (WU) using echocardiography, and the results were compared with invasive PVR measurements using the Bland-Altman analysis. Using receiver-operating characteristics curve analysis, a cutoff value for the Doppler equation was generated to determine PVR >2WU.
RESULTS
J Am Coll Cardiol 2003;41:1021-7
CONCLUSIONS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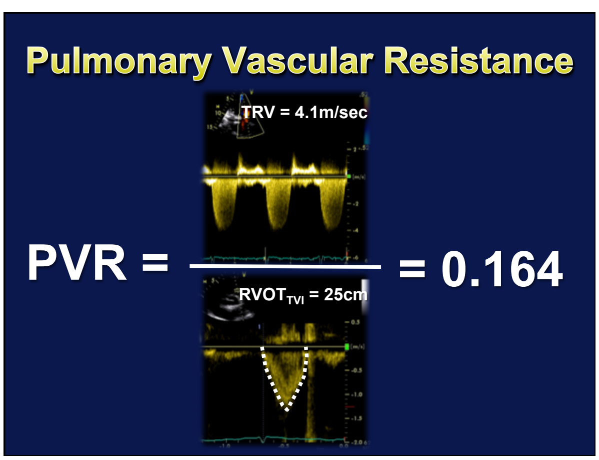
TRV = 4.1m/sec
RVOTTVI = 25cm
0.41). A TRV/TVIRVOT cutoff value of 0.175 had a sensitivity of 77% and a specificity of 81% to determine PVR >2WU.
CONCLUSIONS
Doppler echocardiography may provide a reliable, noninvasive method to determine PVR. (J Am Coll Cardiol 2003;41:1021-7) © 2003 by the American College of Cardiology Foundation


Pulmonary Vascular Resistance
TRV = 4.1m/sec
PVR =
= 0.164
RVOTTVI = 25cm

Pulmonary Vascular Resistance

Echo	PVR Cath
PASP = 77mmHg	PASP = 72mmHg
PVR = $(TRV/RVOT_{tvi})$ 10 + 0.16	PVR = 2.0 Wu
= 1.64 + 0.16	
=1.76 WU	

Simplified formula

$$PVR = 10 \times TRV/TVI_{RVOT}$$

PULMONARY HEMODYNAMICS

Noninvasive Assessment of Pulmonary Vascular Resistance by Doppler Echocardiography

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Noninvasive Assessment of Pulmonary Vascular Resistance by Doppler Echocardiography

of the TRV/TVI_{RVOT} ratio as a correlate of PVR. The role of TRV/TVI_{RVOT} was also compared with that of a new ratio, TRV^2/TVI_{RVOT}, in patients with markedly elevated PVR (>6 WU).

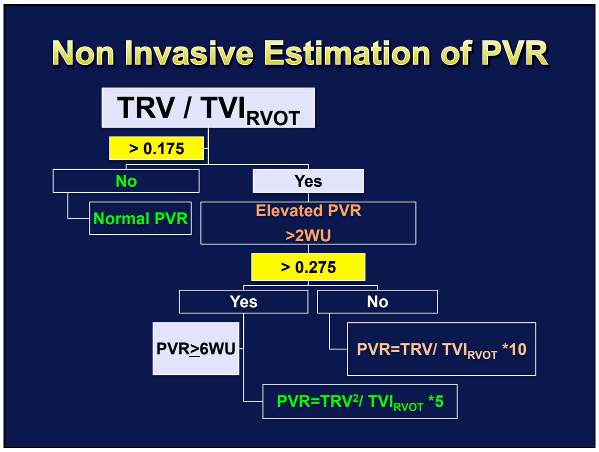
Methods: Data from five validation studies using TRV/TVI_{RVOT} as an estimate of PVR were compared with invasive PVR measurements (PVR_{cath}). Multiple linear regression analyses were generated between PVR_{cath} and both TRV/TVI_{RVOT} and TRV^2/TVI_{RVOT}. Both PVR_{echo} and a new derived regression equation based on TRV^2/TVI_{RVOT}: $5.19 \times TRV^2/TVI_{RVOT} - 0.4$ (PVR_{echo2}) were compared with PVR_{cath} using Bland-Altman analysis. Logistic models were generated, and cutoff values for both TRV/TVI_{RVOT} and TRV^2/TVI_{RVOT} were obtained to predict PVR > 6 WU.

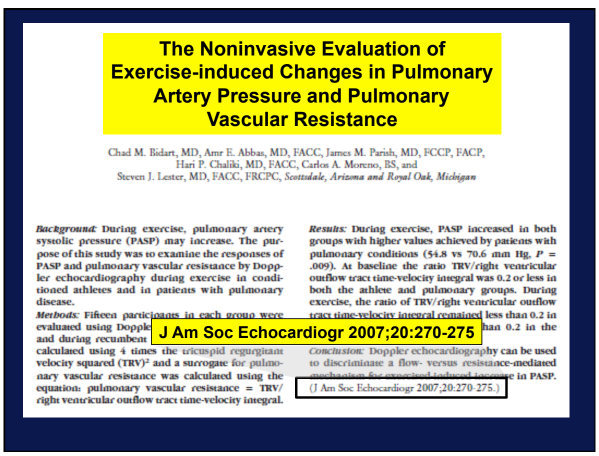
Results: One hundred fifty patients remained in the final analysis. Linear regression analysis between PVR_{cath} and TRV/TVI_{RVOT} revealed a good correlation ($r = 0.76$, $P < .0001$, $Z = 0.92$). There was a better correlation between PVR_{cath} and TRV^2/TVI_{RVOT} ($r = 0.79$, $P < .0001$, $Z = -0.01$) in the entire cohort as well as in patients

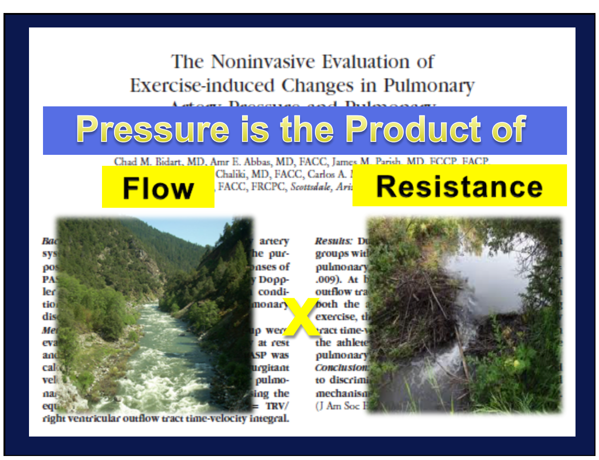
J Am Soc Echocardiogr 2013;26:1170-7

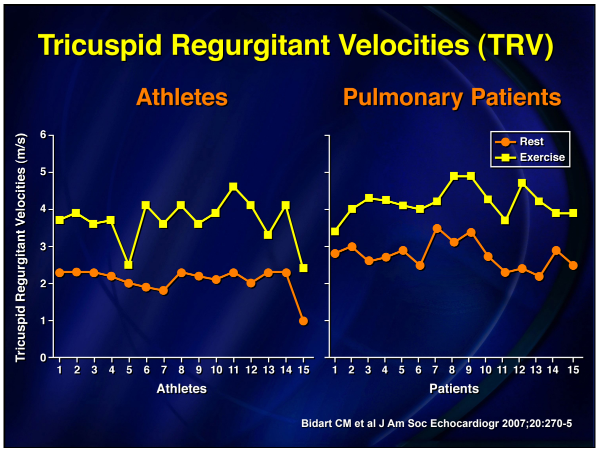
Conclusions: TRV/TVI_{RVOT} is a reliable method to identify patients with elevated PVR. In patients with $TRV/TVI_{RVOT} > 0.275$, PVR is likely > 6 WU, and PVR improved noninvasive estimate of PVR compared with PVR_{echo}. (J Am Soc Echocardiogr 2013;26:1170-7.)

Keywords: Pulmonary vascular resistance, Doppler echocardiography, Pulmonary hypertension

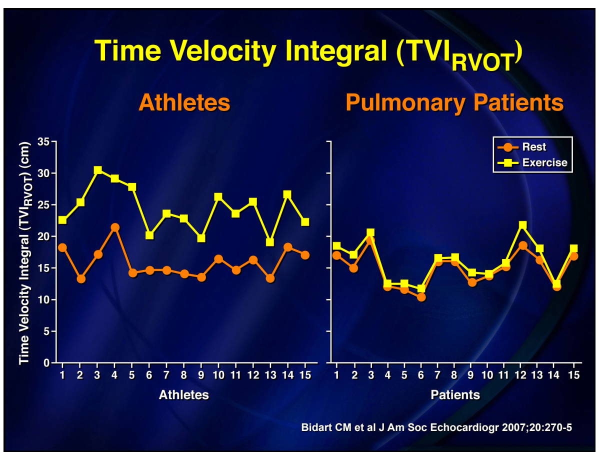

Non Invasive Estimation of PVR
TRV / TVI RVOT
> 0.175
No
Yes
Normal PVR
Elevated PVR
>2WU
> 0.275
Yes
No
PVR≥6WU
PVR=TRV/ TVI RVOT *10
PVR=TRV²/ TVI RVOT *5


The Noninvasive Evaluation of Exercise-induced Changes in Pulmonary Artery Pressure and Pulmonary Vascular Resistance
Chad M. Bidart, MD, Amr E. Abbas, MD, FACC, James M. Parish, MD, FCCP, FACP, Hari P. Chaliki, MD, FACC, Carlos A. Moreno, BS, and Steven J. Lester, MD, FACC, FRCPC, Scottsdale, Arizona and Royal Oak, Michigan
Background: During exercise, pulmonary artery systolic pressure (PASP) may increase. The purpose of this study was to examine the responses of PASP and pulmonary vascular resistance by Doppler echocardiography during exercise in conditioned athletes and in patients with pulmonary disease.
Methods: Fifteen participants in each group were evaluated using Doppler
and during recumbent
calculated using 4 times the tricuspid regurgitant velocity squared (TRV)² and a surrogate for pulmonary vascular resistance was calculated using the equation: pulmonary vascular resistance = TRV/right ventricular outflow tract time-velocity integral.
Results: During exercise, PASP increased in both groups with higher values achieved by patients with pulmonary conditions (54.8 vs 70.6 mm Hg, P = .009). At baseline the ratio TRV/right ventricular outflow tract time-velocity integral was 0.2 or less in both the athlete and pulmonary groups. During exercise, the ratio of TRV/right ventricular outflow tract time-velocity integral remained less than 0.2 in
han 0.2 in the
Conclusion: Doppler echocardiography can be used to discriminate a flow- versus resistance-mediated mechanism for exercised-induced increase in PASP.
(J Am Soc Echocardiogr 2007;20:270-275.)
J Am Soc Echocardiogr 2007;20:270-275

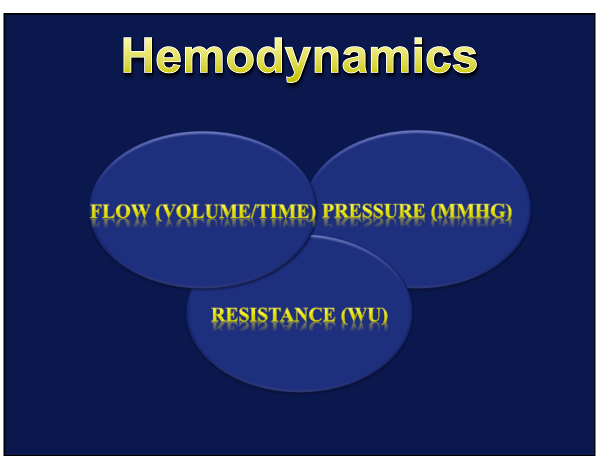

The Noninvasive Evaluation of
Exercise-induced Changes in Pulmonary
Pressure is the Product of
Flow
X
Resistance



Tricuspid Regurgitant Velocities (TRV)
Athletes
Pulmonary Patients
Rest
Exercise
Tricuspid Regurgitant Velocities (m/s)
0 1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Athletes
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Patients
Bidart CM et al J Am Soc Echocardiogr 2007;20:270-5

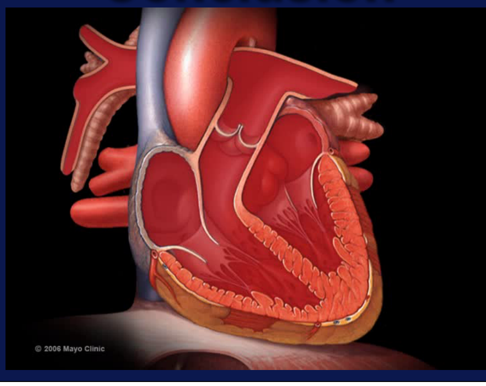


Time Velocity Integral (TVI_{RVOT})
Athletes
Pulmonary Patients
Rest
Exercise
Time Velocity Integral (TVI_{RVOT}) (cm)
0 5 10 15 20 25 30 35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Athletes
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Patients
Bidart CM et al J Am Soc Echocardiogr 2007;20:270-5



Hemodynamics
FLOW (VOLUME/TIME)
PRESSURE (MMHG)
RESISTANCE (WU)

Conclusion



mayo