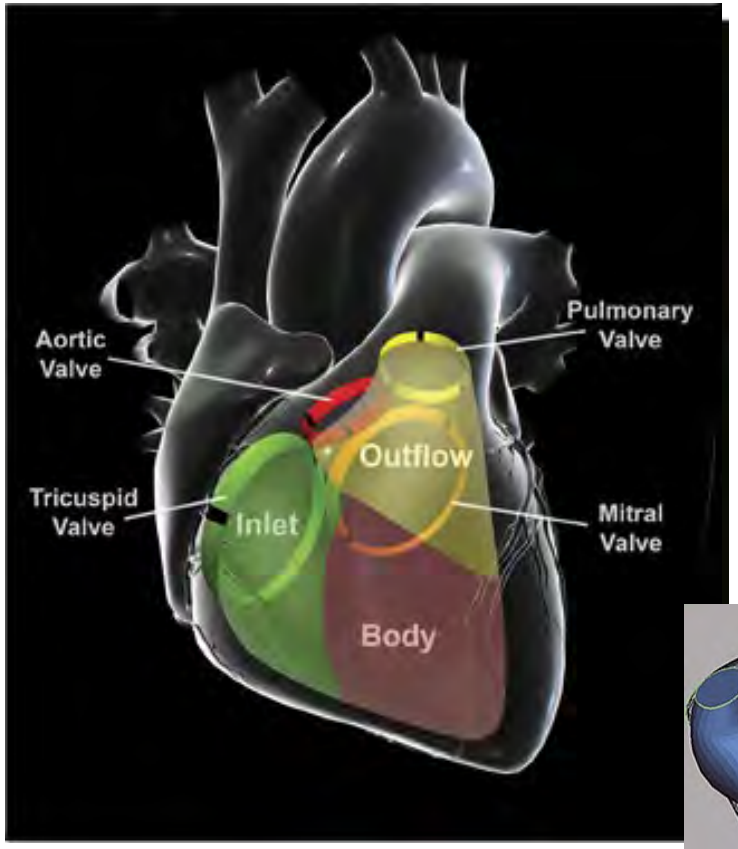
Right Heart Quantification:
- A Focus on the Right Ventricle

J. Todd Belcik, BS, ACS, RDCS (AE) (PE), FASE
Sr. Research Associate/Sr. Research Sonographer
Knight Cardiovascular Institute
Cardiovascular Imaging Research Lab
Oregon Health & Science University
Portland, OR

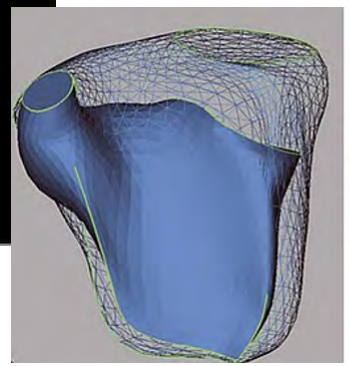
The Right Heart

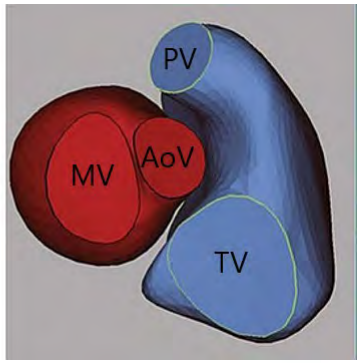


Physiology

- Thin walled
- Crescent shape
- Anatomically subdivided: 1) inflow tract, 2) outflow tract, and 3) apex
- High degree of compliance
- Ability to accommodate large volumes
- Low vascular resistance (PVR ~ 1/10th of SVR)
- Ejection is complex → pronounced base to apex shortening

*** Cannot image all 3 regions in single 2D imaging plane

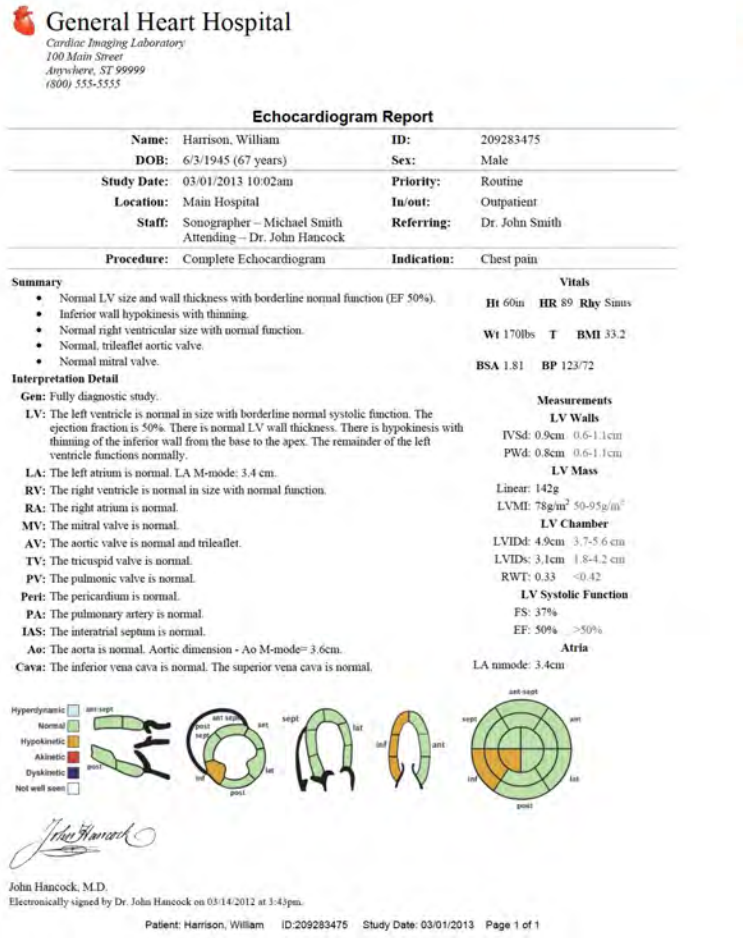




<u>Challenges/Limitations</u>

- Foreshortening/Doppler alignment
- Endocardial border definition (image quality)
- Trabeculations/moderator band
- Single view may not reflect global size

RV Assessment – Report Components



General Heart Hospital
Cardiac Imaging Laboratory
100 Main Street
Anywhere, ST 99999
(800) 555-5555

Echocardiogram Report

Name:	Harrison, William	**ID:**	209283475
DOB:	6/3/1945 (67 years)	**Sex:**	Male
Study Date:	03/01/2013 10:02am	**Priority:**	Routine
Location:	Main Hospital	**In/out:**	Outpatient
Staff:	Sonographer – Michael Smith Attending – Dr. John Hancock	**Referring:**	Dr. John Smith
Procedure:	Complete Echocardiogram	**Indication:**	Chest pain

Summary

- Normal LV size and wall thickness with borderline normal function (EF 50%).
- Inferior wall hypokinesis with thinning.
- Normal right ventricular size with normal function.
- Normal, trileaflet aortic valve.
- Normal mitral valve.

Interpretation Detail

Gen: Fully diagnostic study.
LV: The left ventricle is normal in size with borderline normal systolic function. The ejection fraction is 50%. There is normal LV wall thickness. There is hypokinesis with thinning of the inferior wall from the base to the apex. The remainder of the left ventricle functions normally.
LA: The left atrium is normal. LA M-mode: 3.4 cm.
RV: The right ventricle is normal in size with normal function.
RA: The right atrium is normal.
MV: The mitral valve is normal.
AV: The aortic valve is normal and trileaflet.
TV: The tricuspid valve is normal.
PV: The pulmonic valve is normal.
Peri: The pericardium is normal.
PA: The pulmonary artery is normal.
IAS: The interatrial septum is normal.
Ao: The aorta is normal. Aortic dimension - Ao M-mode= 3.6cm.
Cava: The inferior vena cava is normal. The superior vena cava is normal.

Vitals

Ht 60in **HR** 89 **Rhy** Sinus
Wt 170lbs **T** **BMI** 33.2
BSA 1.81 **BP** 123/72

Measurements

LV Walls
IVSd: 0.9cm 0.6-1.1cm
PWd: 0.8cm 0.6-1.1cm
LV Mass
Linear: 142g
LVMI: 78g/m^2 50-95g/m^2
LV Chamber
LVIDd: 4.9cm 3.7-5.6 cm
LVIDs: 3.1cm 1.8-4.2 cm
RWT: 0.33 <0.42
LV Systolic Function
FS: 37%
EF: 50% >50%
Atria
LA mmode: 3.4cm

Hyperdynamic
Normal
Hypokinetic
Akinetic
Dyskinetic
Not well seen

John Hancock, M.D.
Electronically signed by Dr. John Hancock on 03/14/2012 at 3:43pm.

Patient: Harrison, William ID:209283475 Study Date: 03/01/2013 Page 1 of 1

Parameters required to Perform and Report

- RV size
- RA size
- RV systolic function: (at least one of following)
  - Fractional area change (FAC)
  - Tissue Doppler (S')
  - Tricuspid annular plane systolic excursion (TAPSE)
- RV Myocardial Performance Index (MPI) (with/without)
- Systolic pulmonary artery pressure
- Estimate of RA pressure

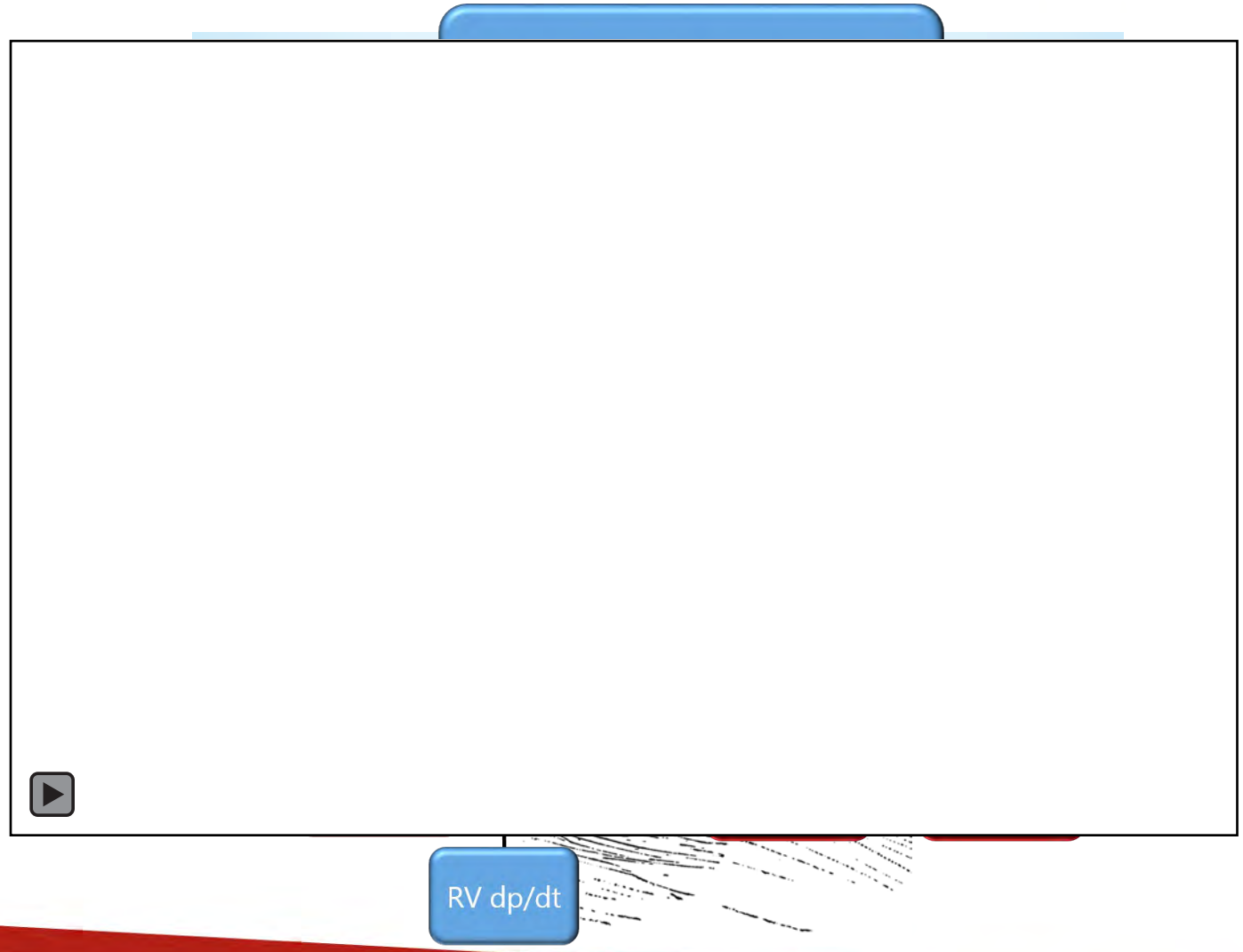
RV Assessment

Functional

- "Visual assessment"
- **Fractional area change (FAC)**
- **TAPSE**
- **Tissue Doppler**
- **Myocardial Performance Index (MPI)**
  - Tei Index
- Strain and strain rate

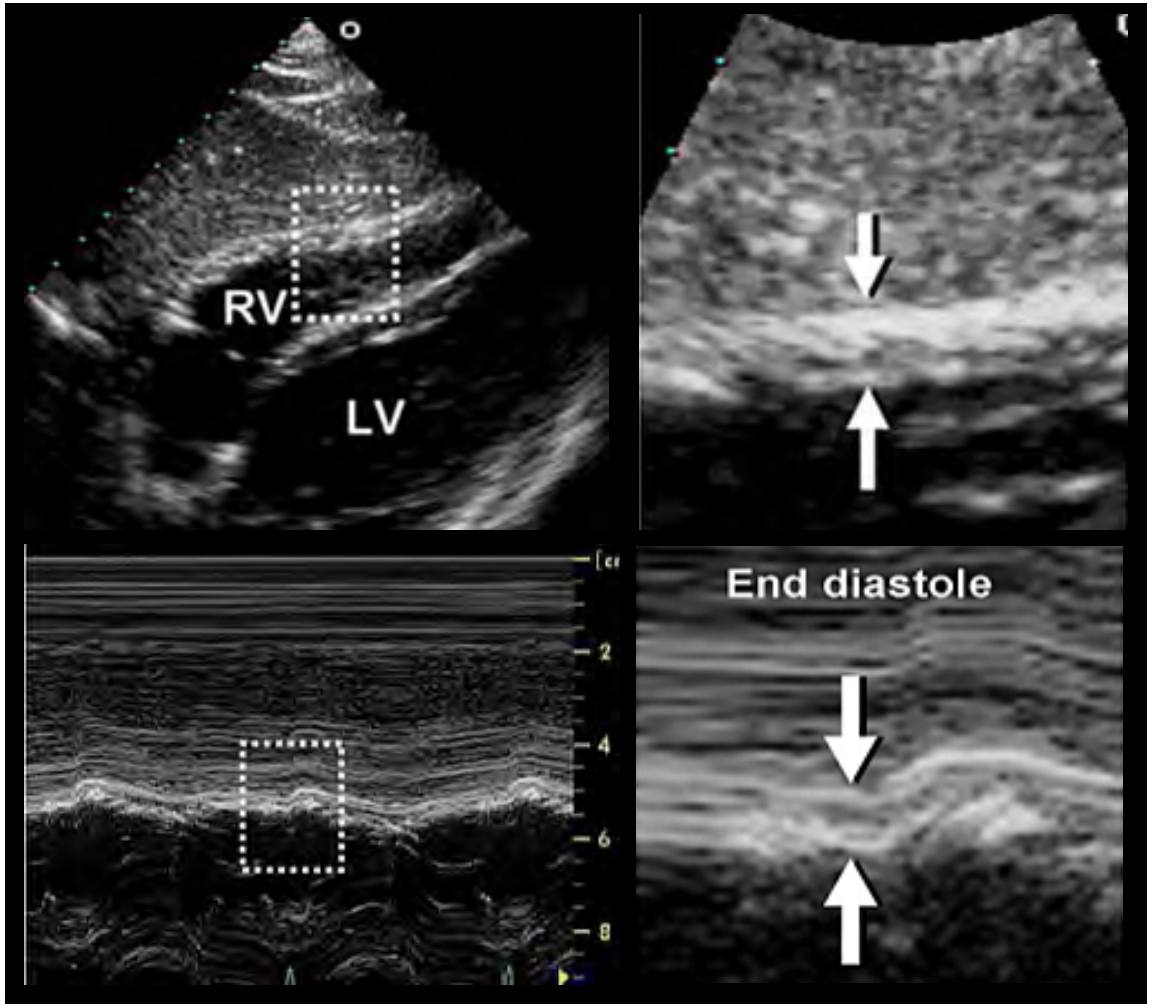
Hemodynamic

- Systolic Pulmonary Artery Pressure
- **Pulmonary Vascular Resistance**



RV Wall Thickness

- Subcostal view by 2D or M-Mode cursor aligned through tip of TV anterior leaflet
- Adjust depth and focus – improved endocardial definition
- Exclude trabeculations, papillary muscle, and epicardial fat
- Minimize harmonic imaging if needed
- RV hypertrophy **>0.5 cm**

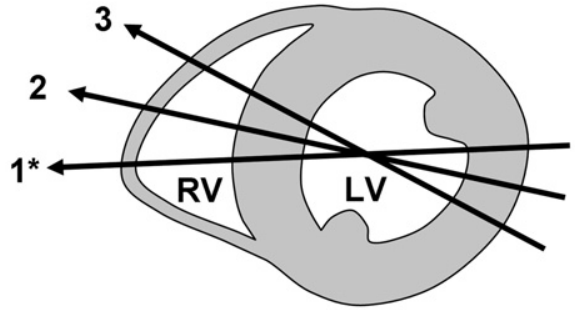


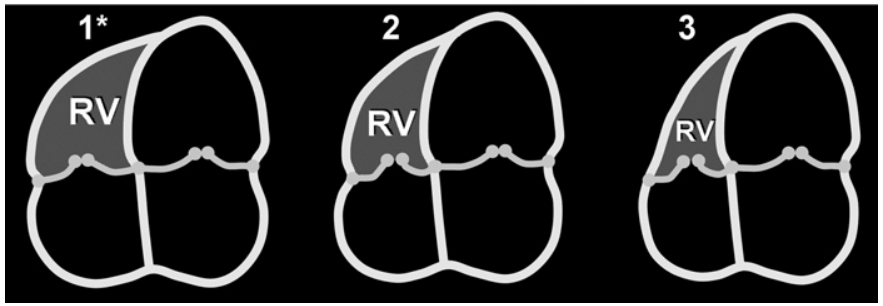
RV Functional Assessment

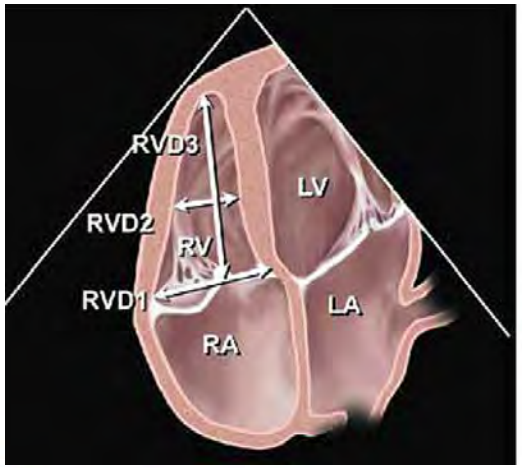
MAJOR limitation is lack of fixed reference points to ensure optimization of the right ventricle

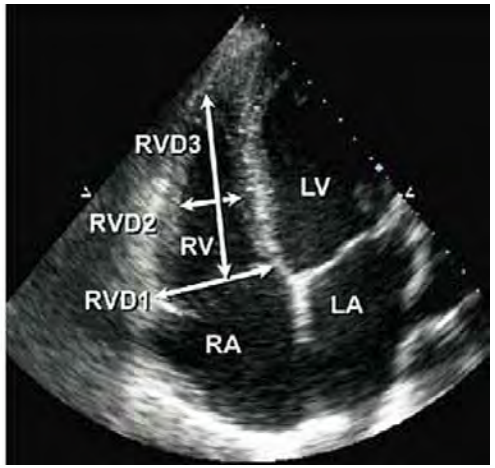
Utilize a "RV focused view" targeted at optimization of RV free wall

- Rotation of transducer until maximal minor distance plane is obtained (avoid underestimation)
- Position transducer over apex with plane through center of LV cavity (avoid overestimation)
- Avoid foreshortening of RV (Ø 5 chamber view)









RV end diastolic dimensions:

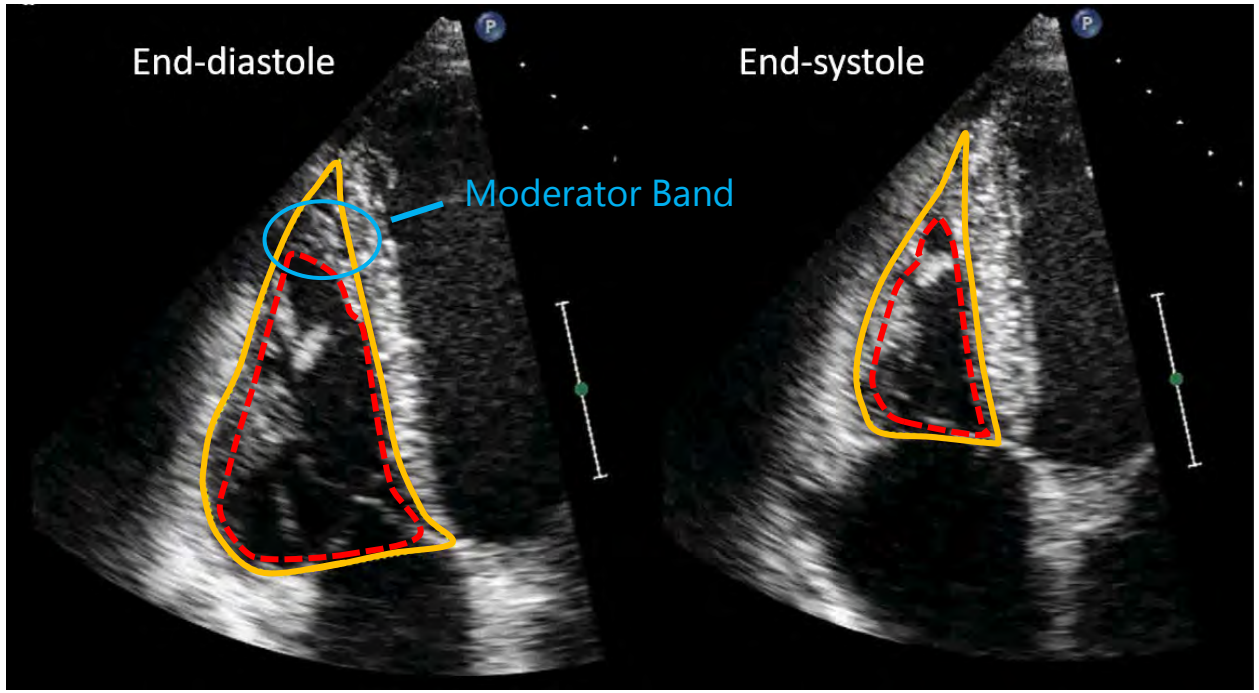
Basal (RVD1): 25-41 mm
Mid (RVD2): 20-35 mm
Length (RVD3): 56-86 mm

RV Fractional Area Change

$$\frac{\textit{End diastolic area} - \textit{End systolic area}}{\textit{End diastolic area}} \; X\ 100$$

- Use RV-focused apical 4 ch view
- Trace RV in diastole and systole
- Trace only the endocardial border
- DO NO trace *around* the moderator band and trabeculations
- Include the entire RV free wall and apex
- Correlates well with RV EF by cMRI

→ Correct technique – yellow
→ Incorrect technique - red



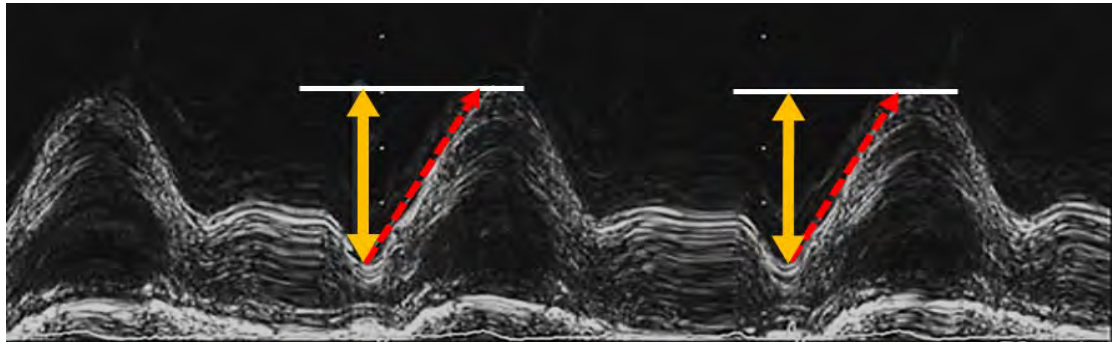
RVAd = 25 cm^2 RVAs= 10 cm^2

RV FAC = (25 – 10)/25 = .60 or 60%

Adapted from Horton KD et al. J Am Soc Echocardiogr 2009;22:776-792

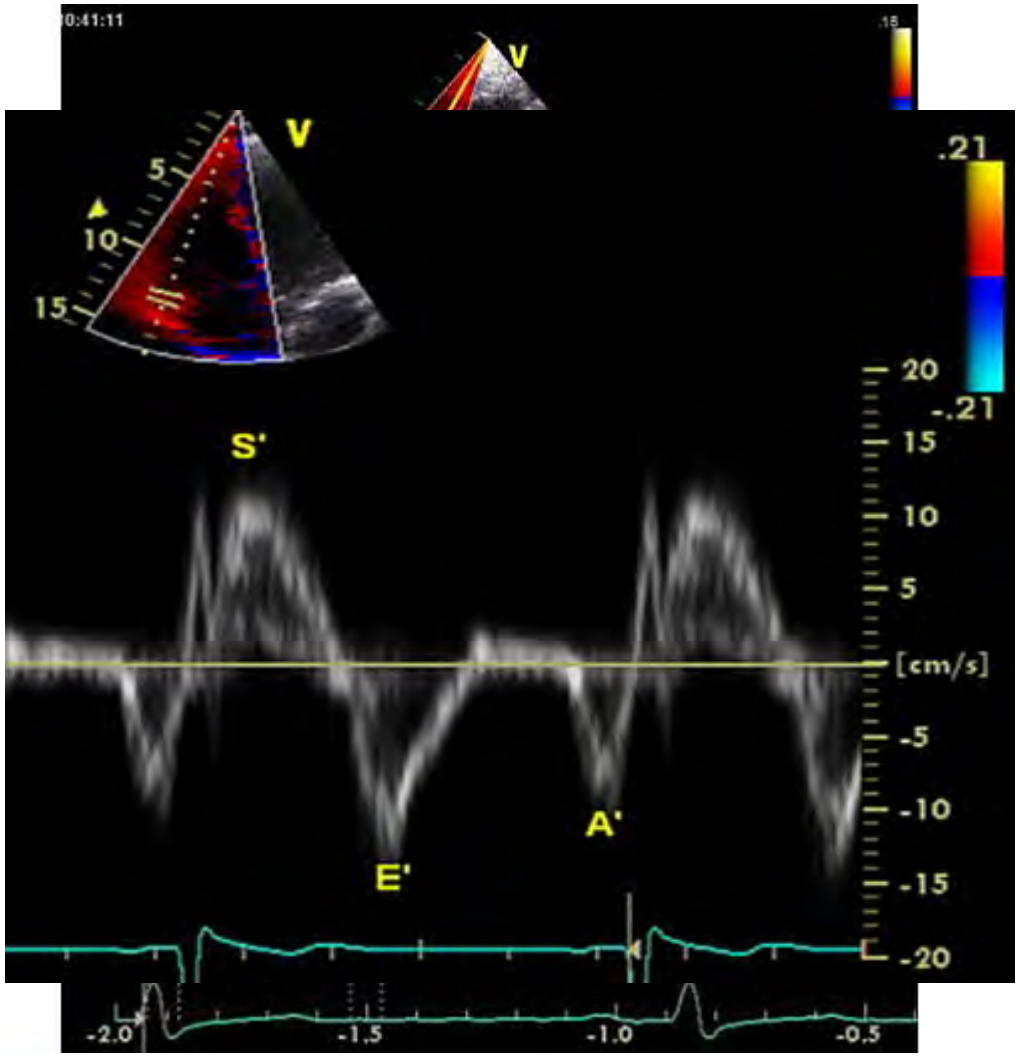
Tricuspid Annular Plane Systolic Excursion (TAPSE)

- 4 chamber view with M-Mode cursor aligned through anterior TV annulus
- *Distance* measurement, not slope or time
- Less image quality dependence
- Simple/Reproducible/Validated
- Both load and angle dependent
- Assumes displacement from single segment represents complex 3D
- TAPSE **<17 mm** = RV systolic dysfunction



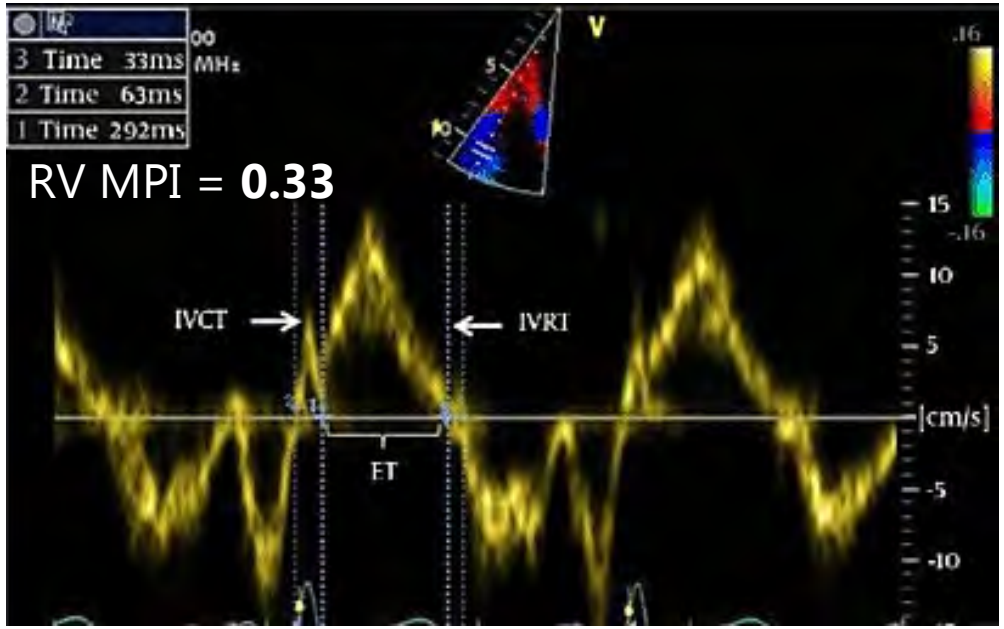
Tissue Doppler

- Apical 4 chamber view with Doppler sample volume placed in either TV annulus or middle of basal segment of RV free wall
- Simple/Reproducible/Validated
- Optimize gain to decrease noise artifact
- Angle dependent/load independent
- Assumes displacement from single segment represents function of entire RV
- Should correlate with TAPSE
- S' velocity **<9.5 cm/s** = RV systolic dysfunction

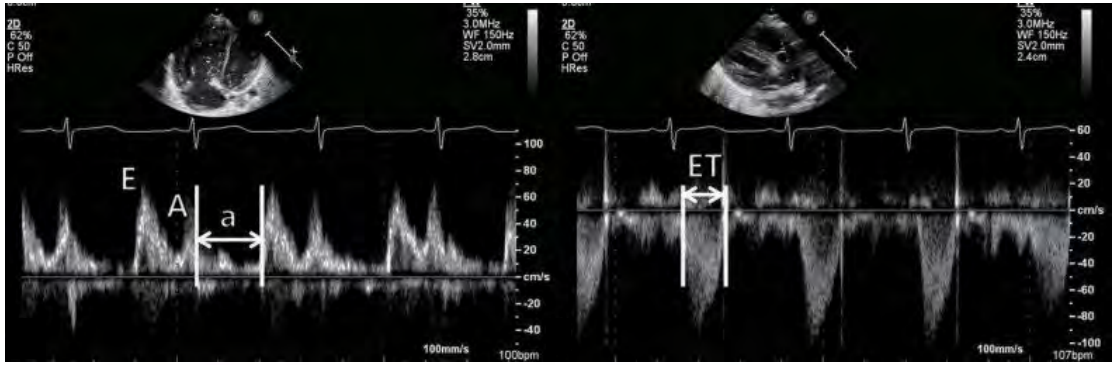


Myocardial Performance Index (Tei)

$$\frac{\text{Isovolumic Relaxation Time (IVRT)} + \text{Isovolumic Contraction time (IVCT)}}{\text{Ejection Time (RVET)}}$$

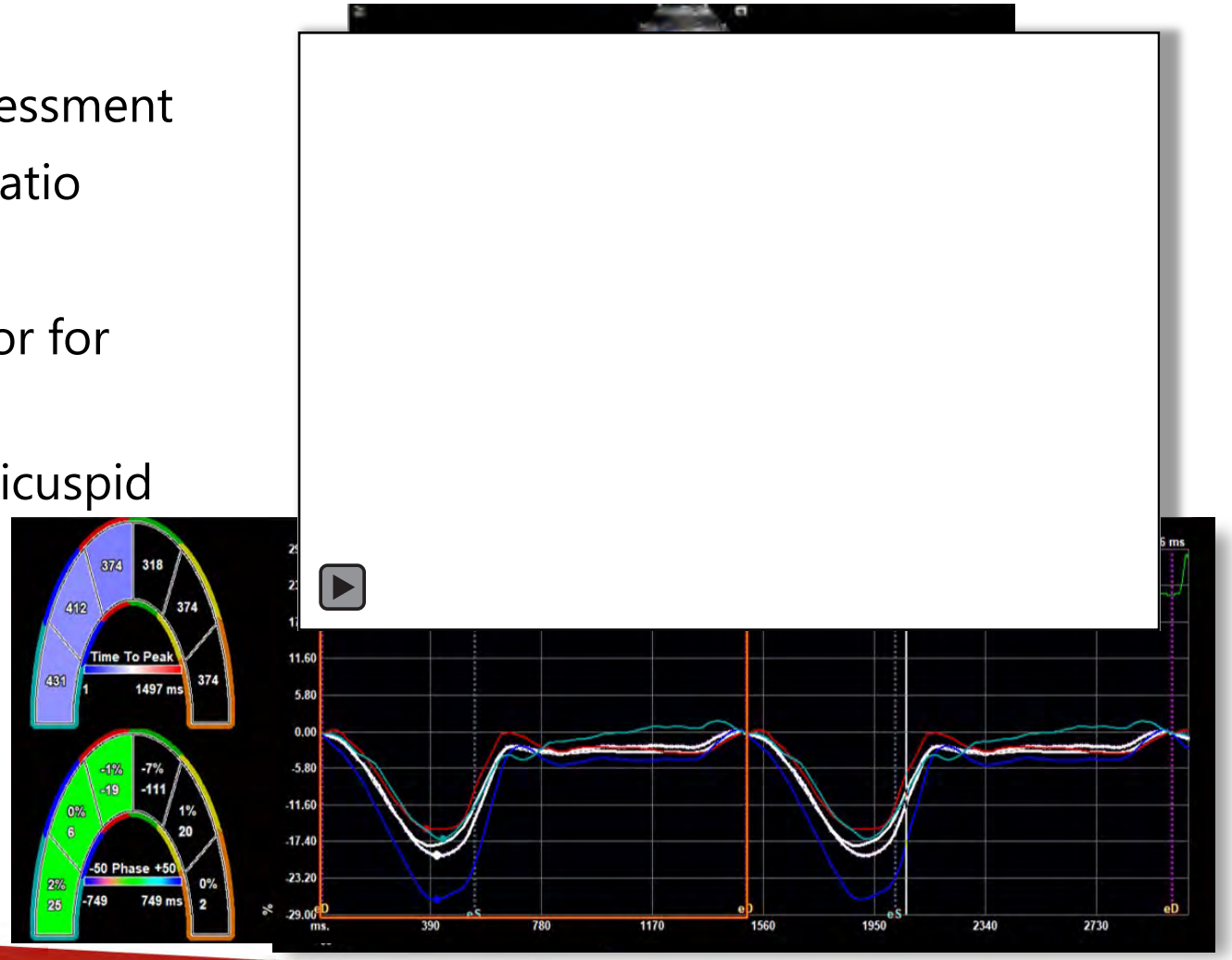


- Global index of both RV systolic and diastolic function
- Doppler of TV inflow/RV outflow (TDI - S′, E′, A′)
- Simple/Reproducible/Validated
- Avoids complex RV geometric assumptions
- Load dependent/unreliable when RAP is elevated
  - less affected than FAC, TAPSE, Strain
- Avoid using with Afib (similar R-to-R intervals)
- Abnormal MPI **>0.40** (PW) and **>.50** (TD)



RV Strain

- Speckle tracking (STE) provides “global” assessment
- Angle independent, better signal-to-noise ratio
- Limited to longitudinal strain
- Use high frame rates (>80 fps), narrow sector for RV free wall, alignment important
- Exclude pericardium and atrial side of the tricuspid annulus (lower values)
- Not yet recommended for clinical use
- Abnormal **< -20%**



Hemodynamic Assessment of Right Ventricle and Pulmonary Circulation

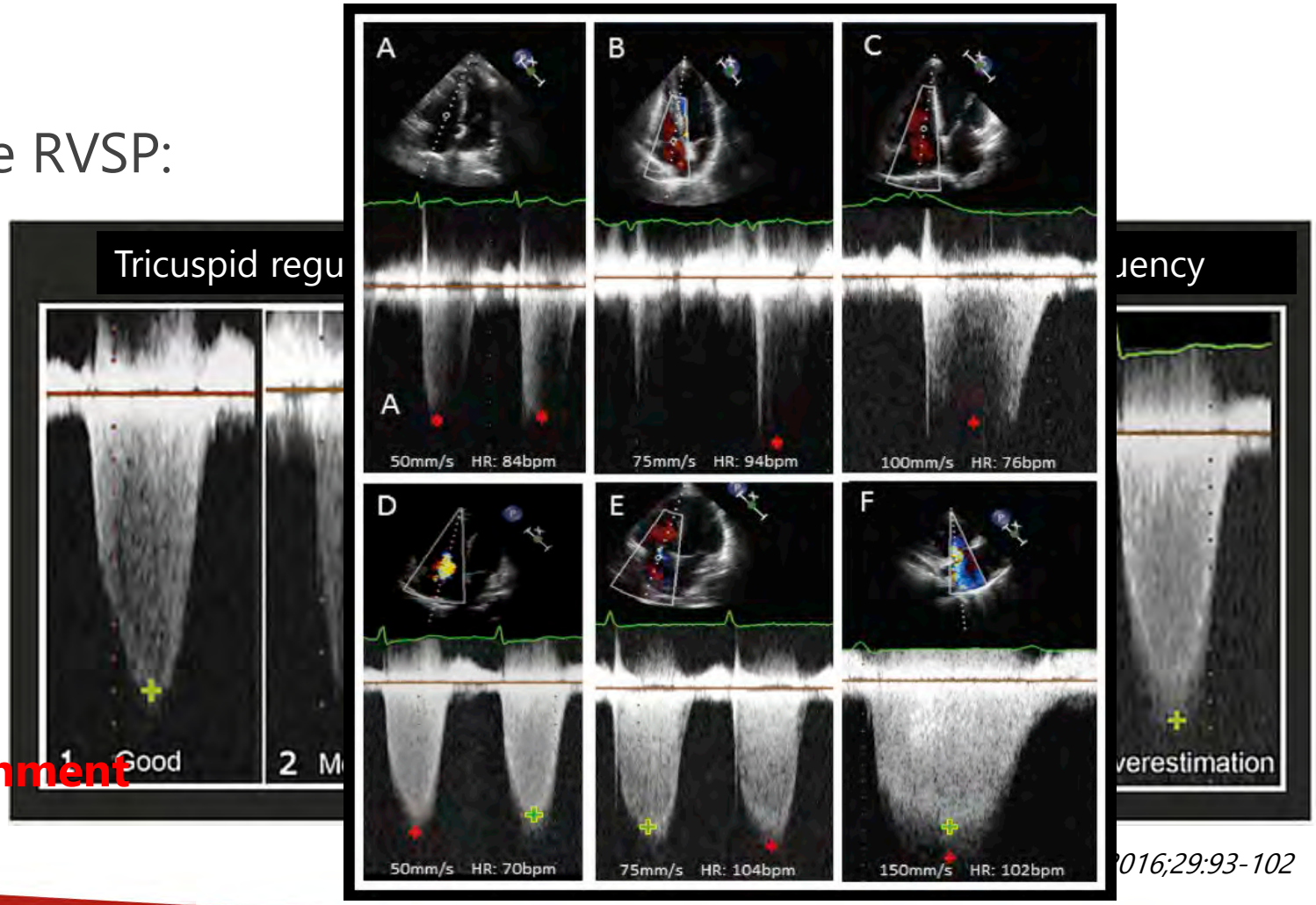
Systolic Pulmonary Artery Pressure

Components for determining the RVSP:

1) TR Max Jet Velocity
   - CW Doppler (multiple views)
2) Right Atrial Pressure (RAP)
   - IVC Size
   - IVC Collapsibility

Modified Bernoulli equation:
*RVSP = 4 * (maximal TR velocity^2) + RAP*

Alignment, Alignment, Alignment

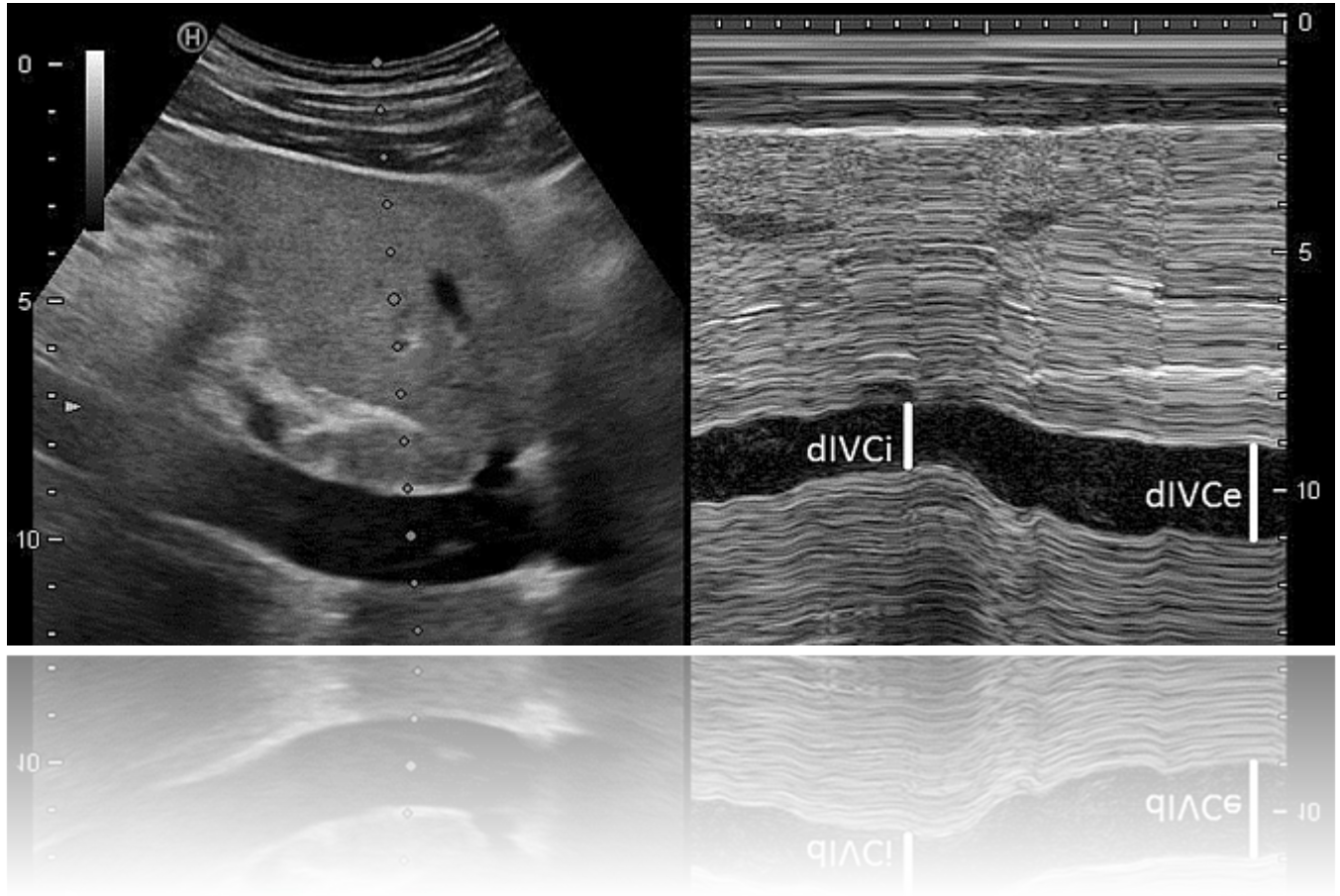


016;29:93-102

Estimation of Right Atrial Pressure

Inferior Vena Cava (IVC):

- should be measured in the long axis subcostal view with the patient in the supine position
- 1 - 2 cm from the junction with the right atrium
  - ***NOT*** *measured at junction of IVC and RA*
- perpendicular to IVC LAX, inner to inner edge
- Brief sniff to illicit inspiratory response

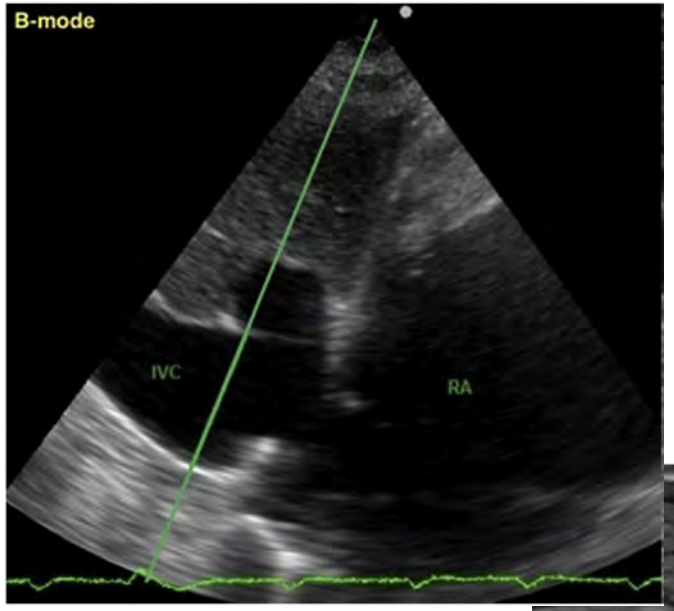


IVC Collapsibility

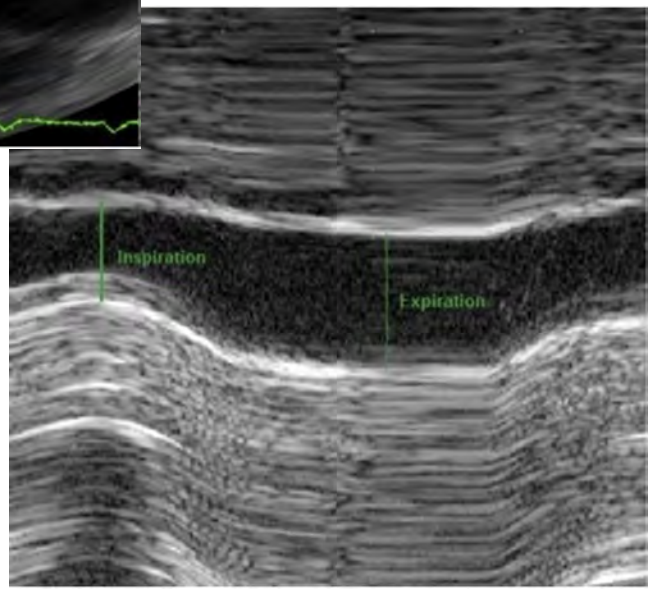
Normal: < 2.1 cm that collapses >50% with a sniff suggests RAP of **3 mm Hg** (range, 0–5 mm Hg)

High: > 2.1 cm that collapses < 50% with a sniff suggests RAP of **15 mm Hg** (range, 10–20 mm Hg)

Intermediate: diameter and collapse do not fit, use RAP of **8 mm Hg** (range, 5–10 mm Hg)



- Young athletes
- Ventilator support



Variables	Normal 0 – 5 mmHg (3 mmHg)	Intermediate 5 – 10 mmHg (8 mmHg)		High 10 – 20 mmHg (15 mmHg)
IVC Diameter (cm)	≤ 2.1 cm	≤2.1 cm	> 2.1 cm	> 2.1 cm
IVC Collapse with sniff (%)	> 50%	< 50%	> 50%	< 50%
2° indices of ↑RAP				- RA enlargement - RV hypertrophy - Hepatic vein flow S/D <1 - Tricuspid E/e' >6 - Restrictive filling

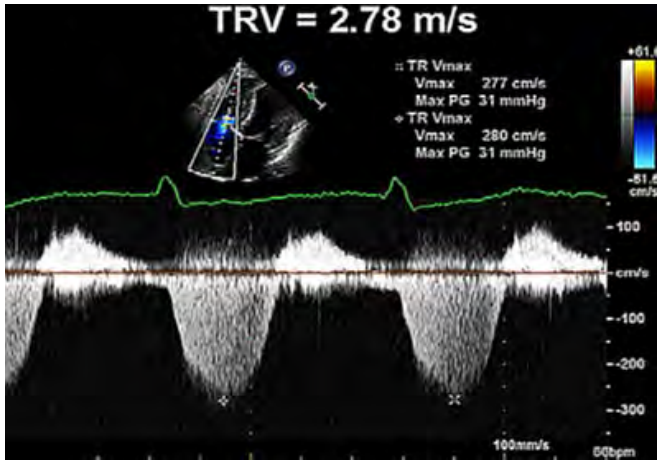
> 2.1 cm – abnormal
< 50% - abnormal

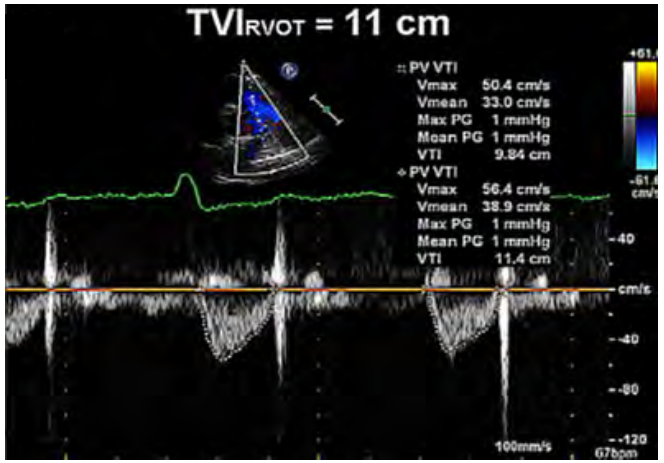
Ceruti S et al. British Journal of Anaesthesia, 120(1): 101e108 (2018)

Pulmonary Vascular Resistance

$$\frac{\textit{TR peak velocity}}{\textit{RVOT VTI}} \; \textit{x 10 + 0.16}$$

- Used to evaluate response to pharmacologic therapy (CHF), heart/liver transplant W/U, predicting early/late clinical outcomes (CHD)
- Doppler of TV regurgitation and RV outflow
  - use agitated saline/UEA to enhance TR jet profile
- Simple ratio: TR peak velocity to RVOT VTI (≤ 0.015)
- Confounding issues in CHD and SV (low/high)
- Normal PVR = **<1.5** WU (120 dynes cm/s^2)
- Significant PAH **>3.0** WU (240 dynes cm/s^2)





2.78/11.4 = 0.2439

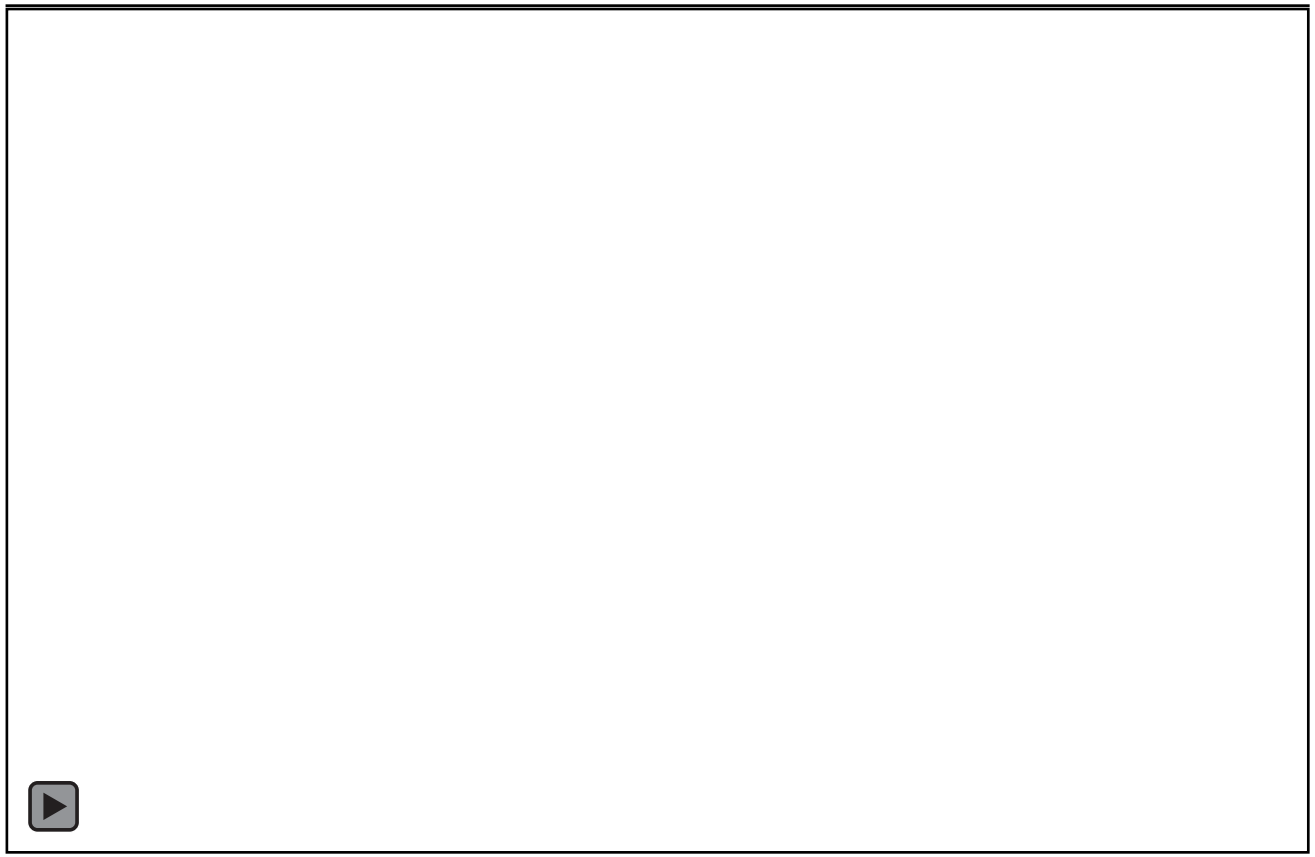
PVR_{ECHO} = 0.2439 × 10 + 0.16

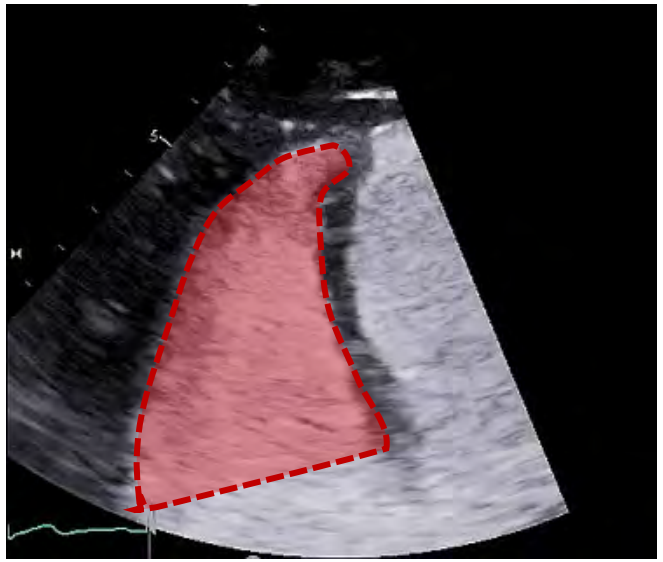
PVR_{ECHO} = **2.60** *WU*

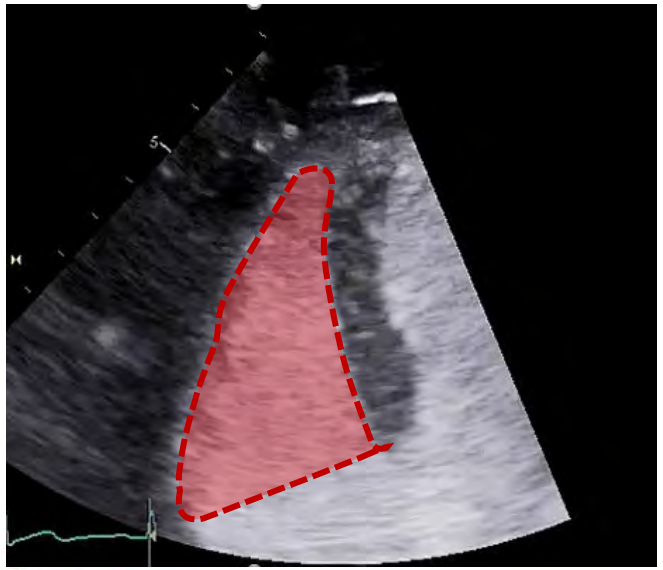
PVR_{ECHO} = **207.89** *dynes cm/s^2*

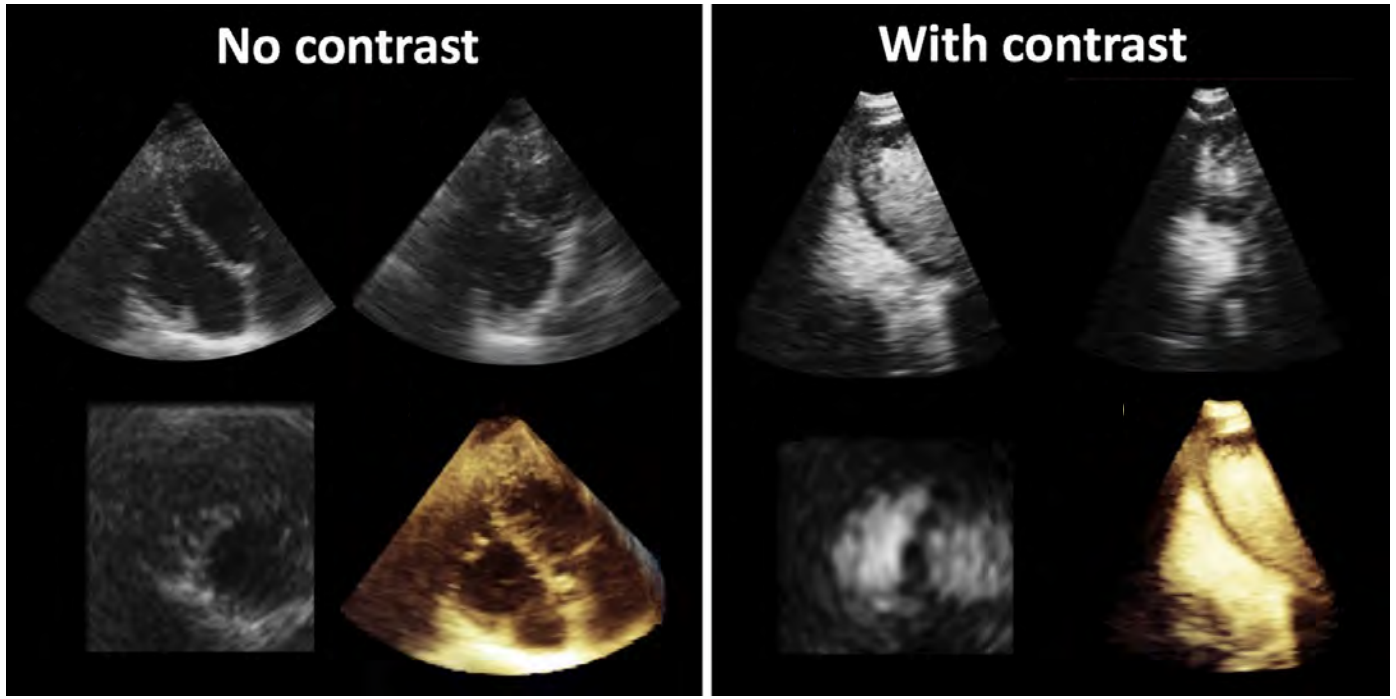
Rudski LG et al. J Am Soc Echocardiogr 2010;23:685-713

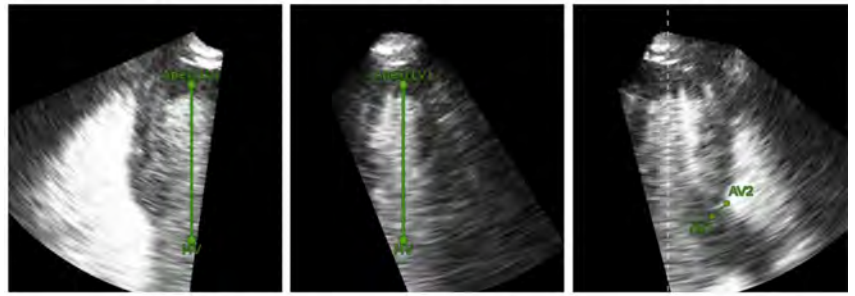
Utility of UEA's in RV Assessment

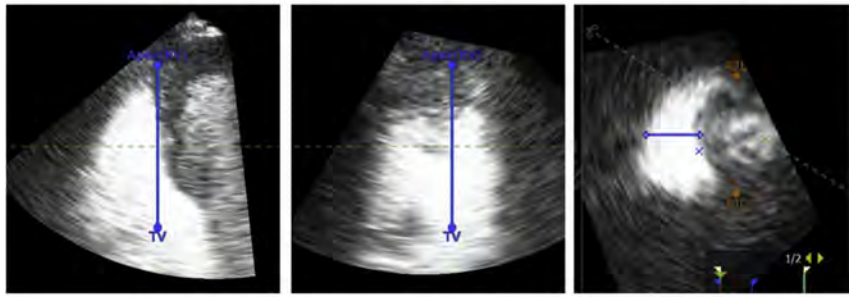












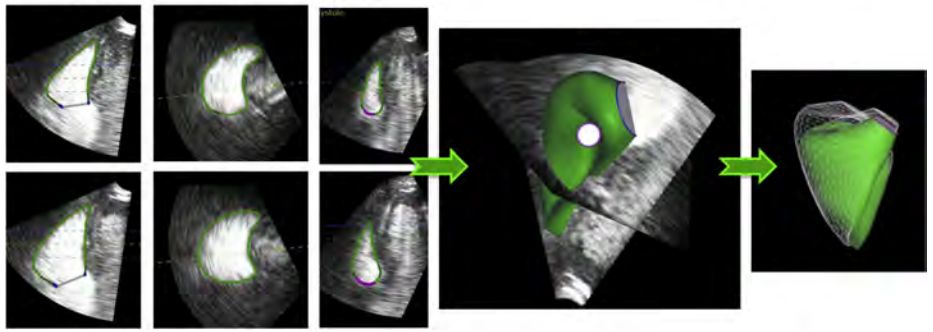


Table 1 RV volumes and function measurements by CMR and 3D echocardiography with and without contrast and intertechnique agreement ($N = 30$)

	CMR	Echocardiography, no contrast			*P* value between echocardiography biases	Echocardiography with contrast		
Measurement	Mean ± SD	Mean ± SD	*r* value to CMR	Bias to CMR, mean ± SD		Mean ± SD	*r* value to CMR	Bias to CMR, mean ± SD
EDV (mL)	192 ± 56	156 ± 49	0.90	−36 ± 25	.00	176 ± 46	0.92	−16 ± 23
ESV (mL)	103 ± 44	79 ± 35	0.92	−23 ± 18	.00	92 ± 36	0.94	−10 ± 16
RVEF (%)	47.7 ± 10	50.5 ± 11	0.70	2.7 ± 8.1	.25	48.4 ± 11	0.87	0.7 ± 5.5

Medvedofsky D et al. J Am Soc Echocardiogr 2017;30:1193-202

Summary

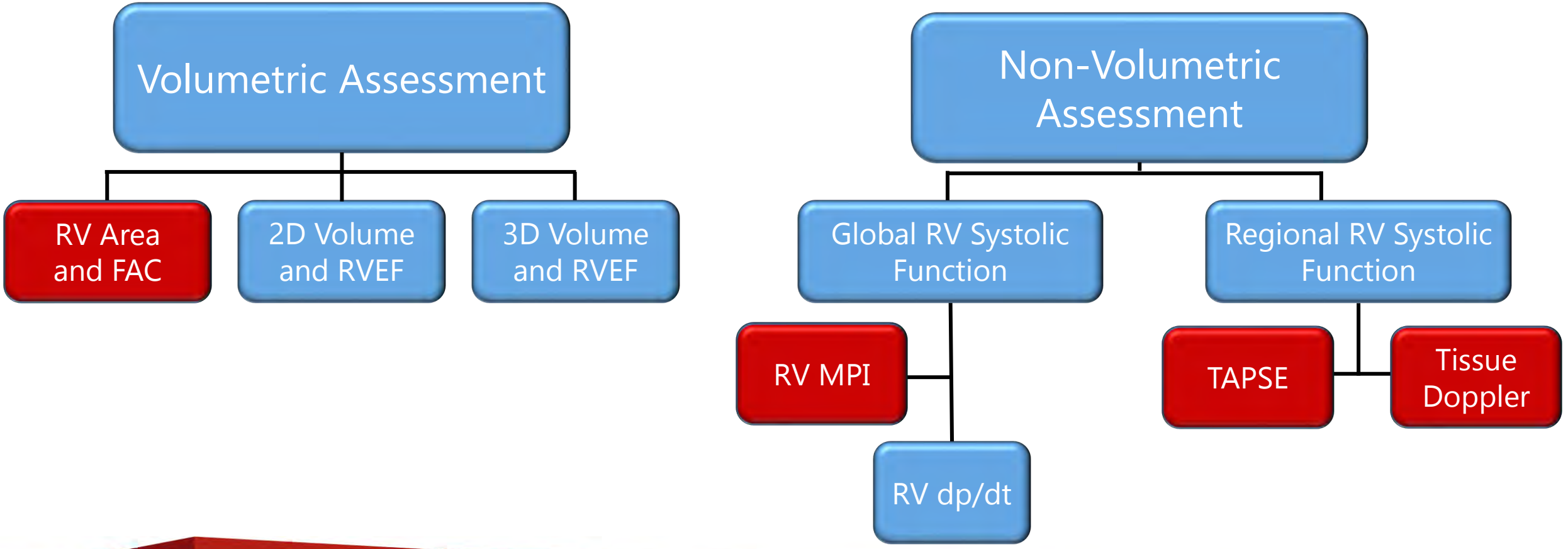
- RV diameter > 42 mm at the base and > 35 mm at the mid level indicates RV dilatation and longitudinal dimension > 86 mm indicates RV enlargement
- RV wall thickness > 5 mm indicates RV hypertrophy (RVH) and may suggest RV pressure overload in the absence of other pathologies
- TR velocity > 2.8 to 2.9 m/s, corresponding to SPAP of approximately 36 mmHg, assuming an RA pressure of 3 to 5mmHg, indicates elevated RV systolic and PA pressure.

<u>RV dysfunction:</u>

- Two-dimensional (2D) FAC < 35% indicates RV systolic dysfunction.
- RIMP > 0.40 by pulsed Doppler and > 0.55 by tissue Doppler
- S' velocity < 10 cm/s
- TAPSE < 16 mm

Alignment, Alignment, Alignment

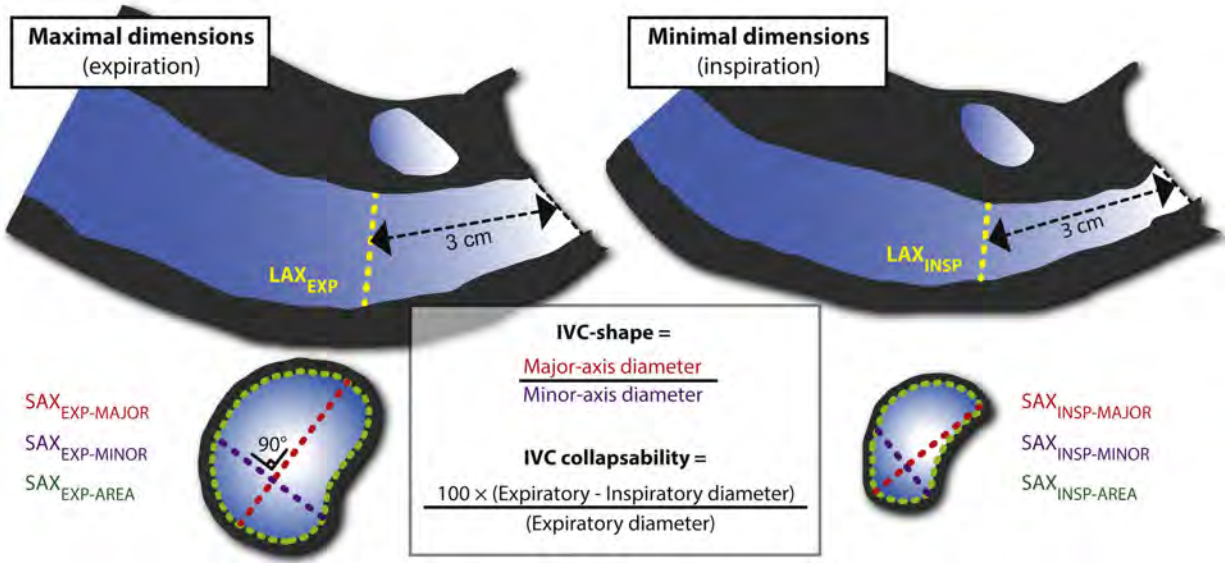
RV Assessment

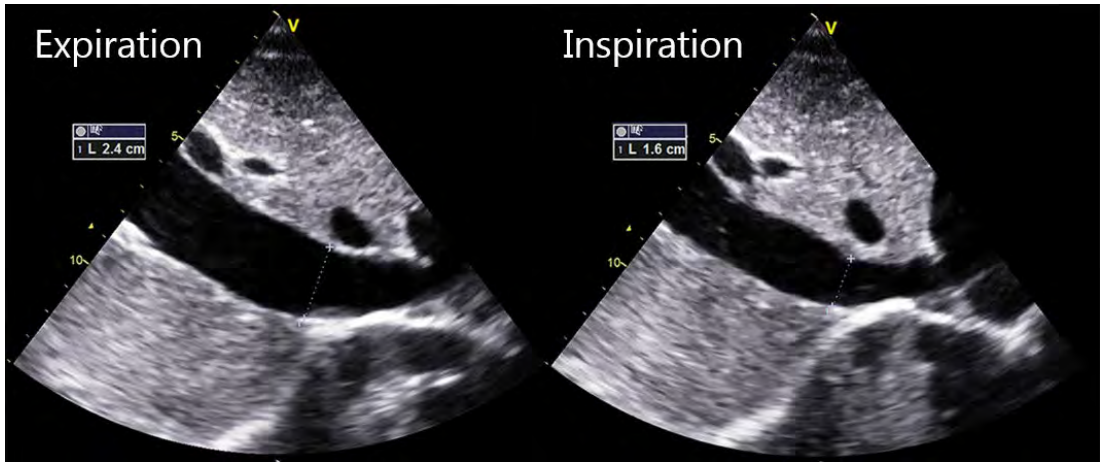


IVC Collapsibility Index

$$\frac{\textit{Max diameter}_{\textit{Expir}} - \textit{Min diameter}_{\textit{Inspir}}}{\textit{Max diameter}_{\textit{Exert}}} \; X\ 100$$

In endurance athletes, a dilated IVC is suggestive of a physiologic adaptation to repeated, intermittent volume loading and not to reflect an increased RA pressure





$$\frac{2.4 - 1.6}{2.4} = 0.33 \text{ or } 33.33\%$$

Hedman K et al. Ultrasound in Med. & Biol., Vol. 42, No. 12, pp. 2794–2802, 2016