UNIUNEA EUROPEANĂ
GUVERNUL ROMÂNIEI
Fondul Social European
POSDRU 2007-2013
Instrumente Structurale
2007-2013
GUVERNUL ROMÂNIEI
MINISTERUL MUNCII, FAMILIEI, PROTECŢIEI SOCIALE
ŞI PERSOANELOR VÂRSTNICE
OIRPOSDRU REGIUNEA CENTRU
UNIVERSITATEA DE MEDICINĂ ŞI FARMACIE "CAROL DAVILA" BUCUREŞTI

AD-COR Program inovativ de formare in domeniul cardiologiei pediatrice
POSDRU/179/3.2/S/152012

***Data:*23-11-2015**

MODUL TEORETIC

Right ventricular physiology and Phatophysiology

Imputernicit: Prof. Dr. Tammam Youssef

Activitate prestata de I.R.C.C.S. POLICLINICO SAN DONATO – MILANO, ITALIA in baza contractului nr. 18/22144/29.07.2015

UNIUNEA EUROPEANĂ

GUVERNUL ROMÂNIEI

Fondul Social European
POSDRU 2007-2013

Instrumente Structurale
2007-2013

GUVERNUL ROMÂNIEI
MINISTERUL MUNCII, FAMILIEI, PROTECȚIEI SOCIALE ȘI PERSOANELOR VÂRSTNICE
OIRPOSDRU REGIUNEA CENTRU

UNIVERSITATEA DE MEDICINĂ ȘI FARMACIE "CAROL DAVILA" BUCUREȘTI

Acest material a fost documentat/ validat/ prezentat la sesiunile de formare în cadrul proiectului *„AD-COR Program inovativ de formare în domeniul cardiologiei pediatrice”* - POSDRU/179/3.2/S/152012, proiect cofinanțat din Fondul Social Operațional Sectorial Dezvoltarea Resurselor Umane 2007-2013.

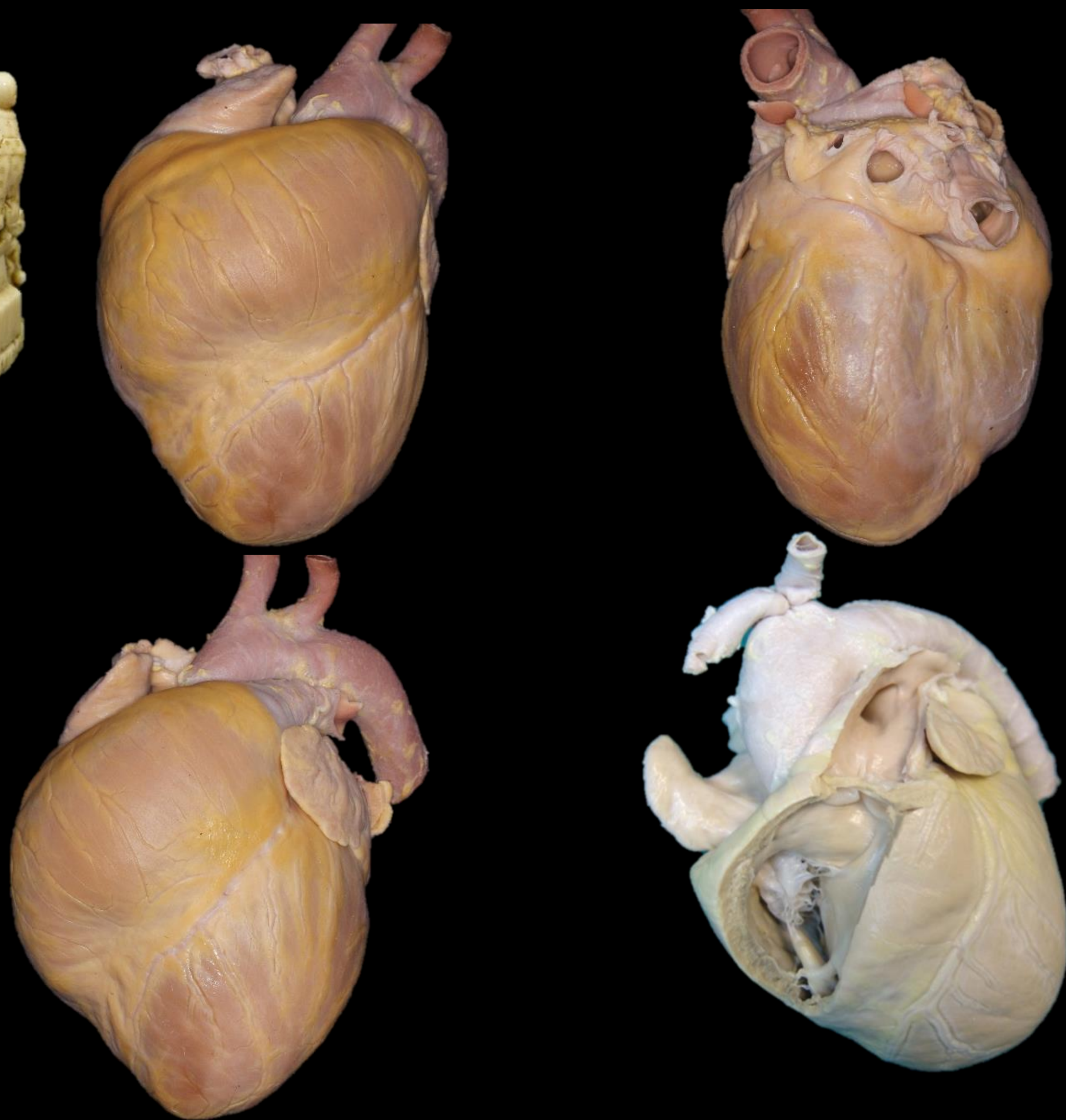
Beneficiar: Universitatea de Medicină și Farmacie „Carol Davila” București

RIGHT VENTRICULAR PHYSIOLOGY AND PHATOPHYSIOLOGY

Claudio Bussadori DVM, MD, PhD, Dipl. ECVIM (Cardiology)

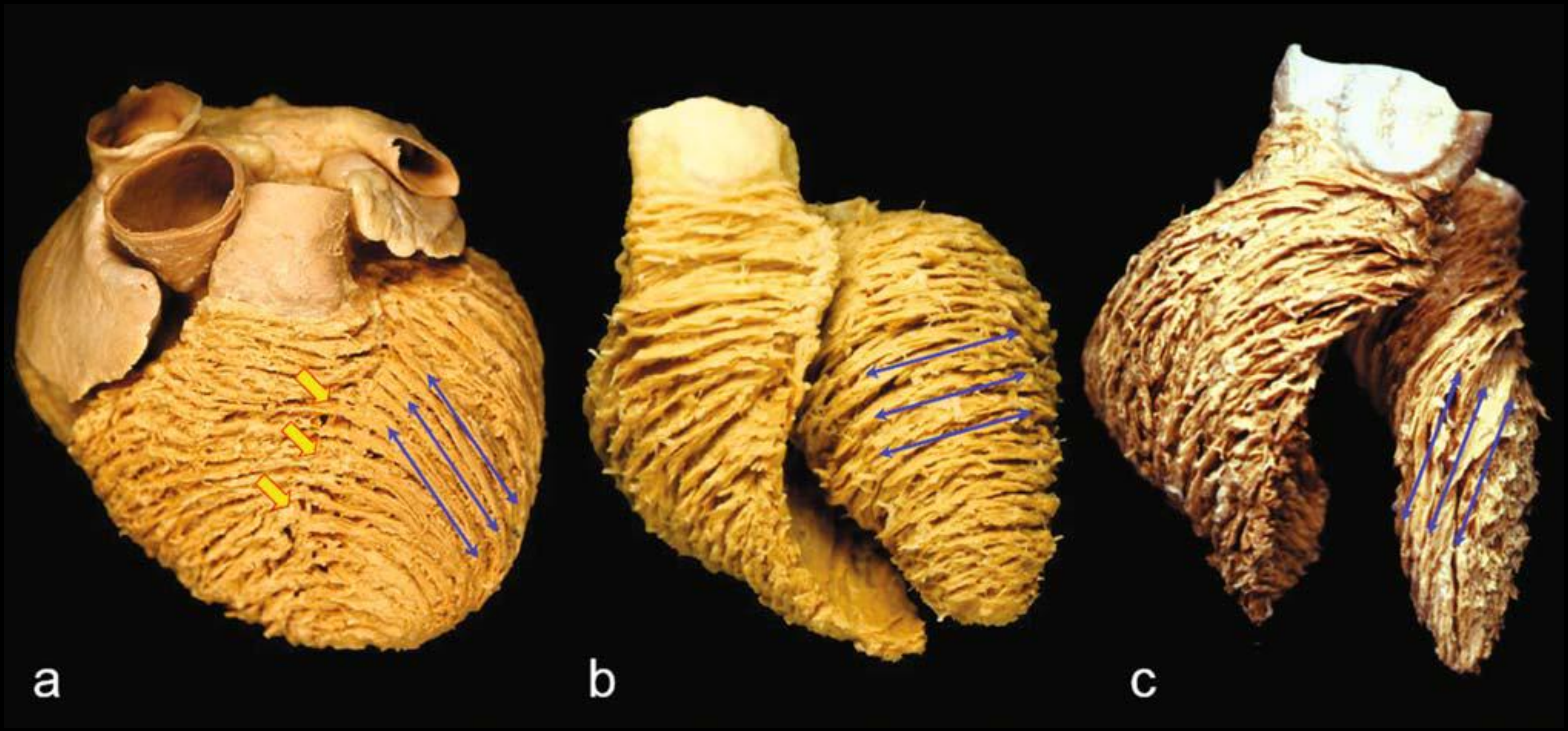
Department of Pediatric Cardiology and Adult with Congenital Heart Disease San Donato Hospital Milano Italy

RIGHT VENTRICULAR STRUCTURE



Rudski LG, Afilalo J. The blind men of indostan and the elephant in the echo lab. *J Am Soc Echocardiogr*. 2012;25:714-717

RIGHT VENTRICULAR STRUCTURE



RV CONTRACTION

1. Inlet and trabeculated myocardium
2. Infundibulum (approximately 25 to 50 ms apart)

Contraction of the infundibulum is of longer duration than contraction of the inflow region

The RV contracts by 3 separate mechanisms

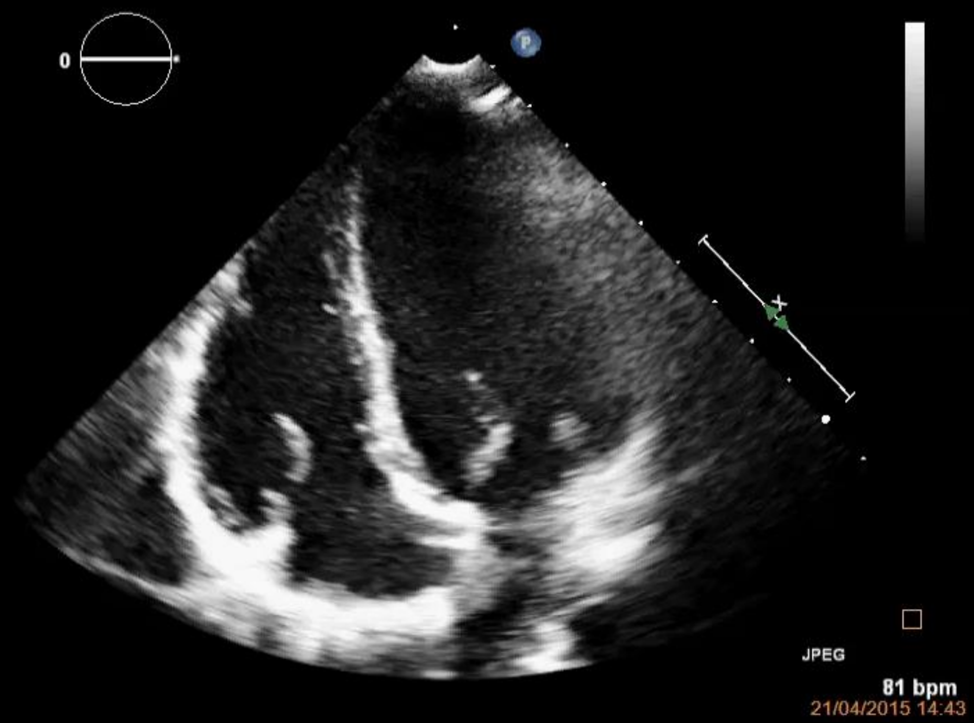
1. Inward movement of the free wall, which produces a bellows effect
2. Contraction of the longitudinal fibers, which shortens the long axis and draws the tricuspid annulus toward the apex
3. Traction on the free wall at the points of attachment secondary to LV contraction

RV CONTRACTION

Greater longitudinally than radially.

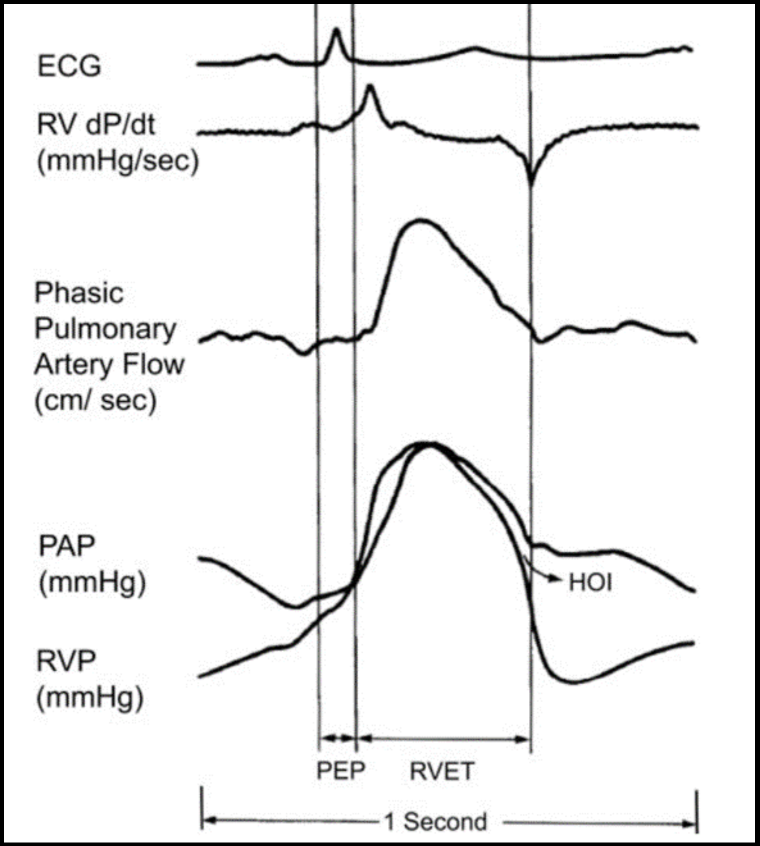
Twisting do not contribute significantly to RV contraction.

Moreover, because of the higher surface-to- volume ratio of the RV, a smaller inward motion is required to eject the same stroke volume.

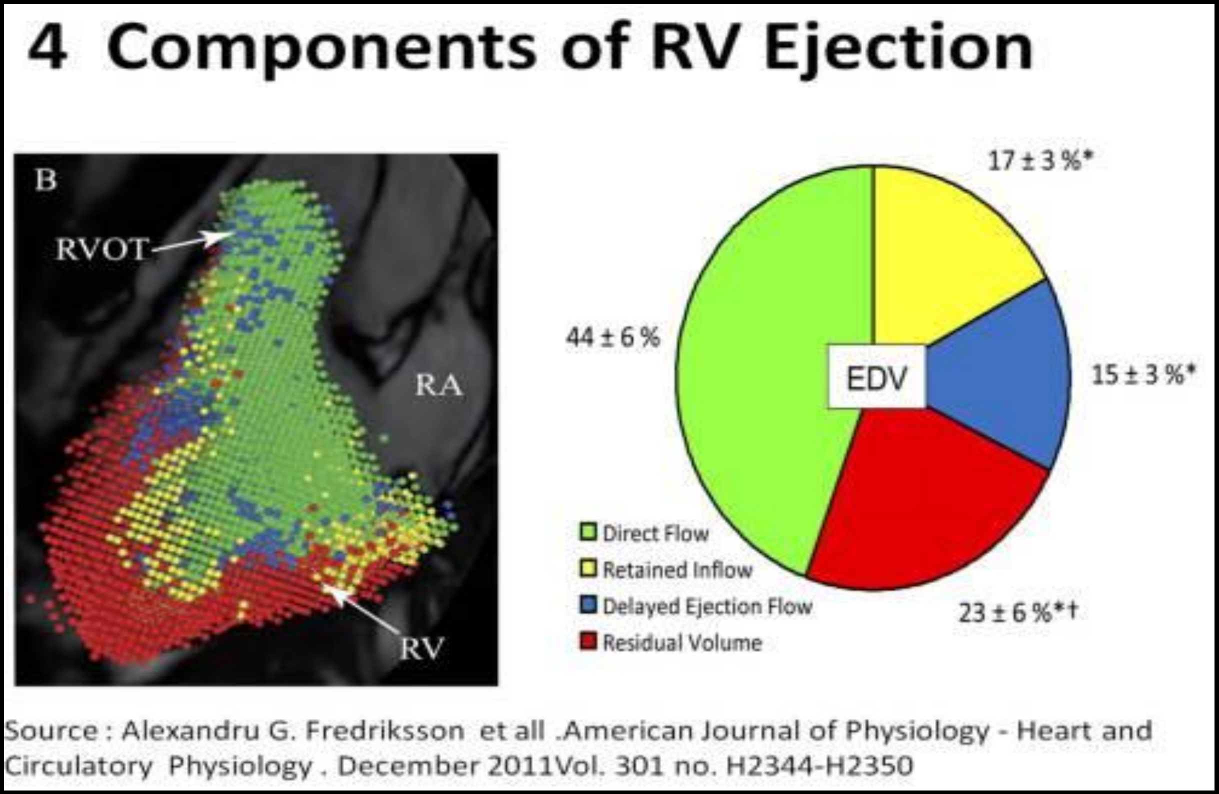


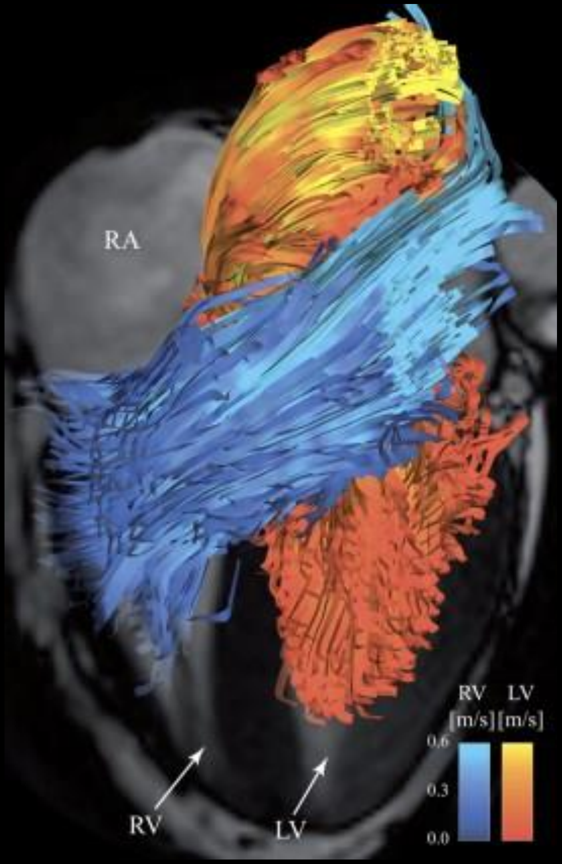
RV SYSTOLIC EJECTION

- Right-sided pressures lower than left-sided.
- RV isovolumic contraction time is shorter.
- End-systolic flow may continue in the presence of a negative ventricular-arterial pressure gradient (hangout interval)



RV FLOW





Fredriksson AG, Zajac J, Eriksson J, Dyverfeldt P, Bolger AF, Ebbers T, Carlhall CJ. 4-d blood flow in the human right ventricle. *Am J Physiol Heart Circ Physiol*. 2011;301:H2344-2350

LONGITUDINAL RV CONTRACTION

4Chambers

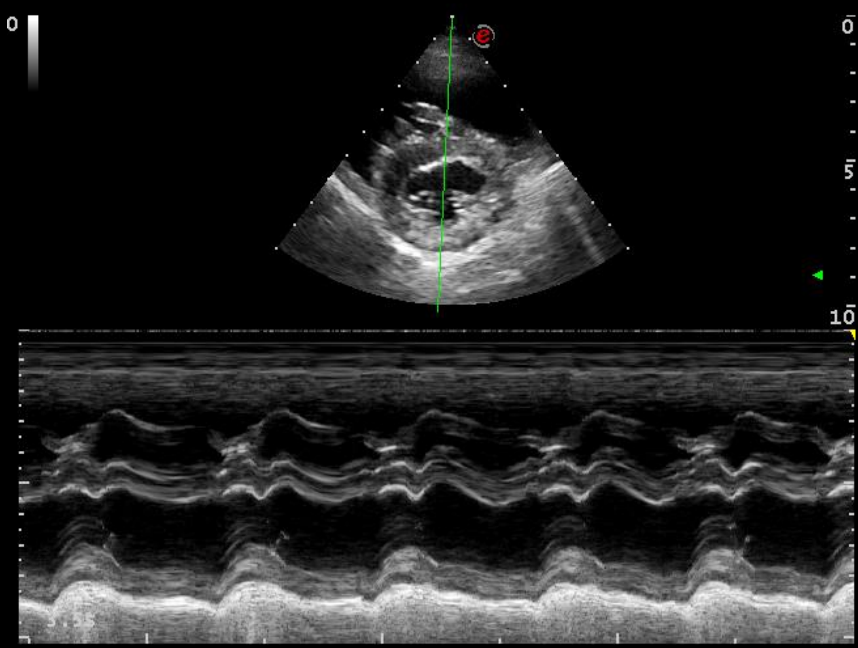
RVOT

VENTRICULAR INTERDEPENDENCE

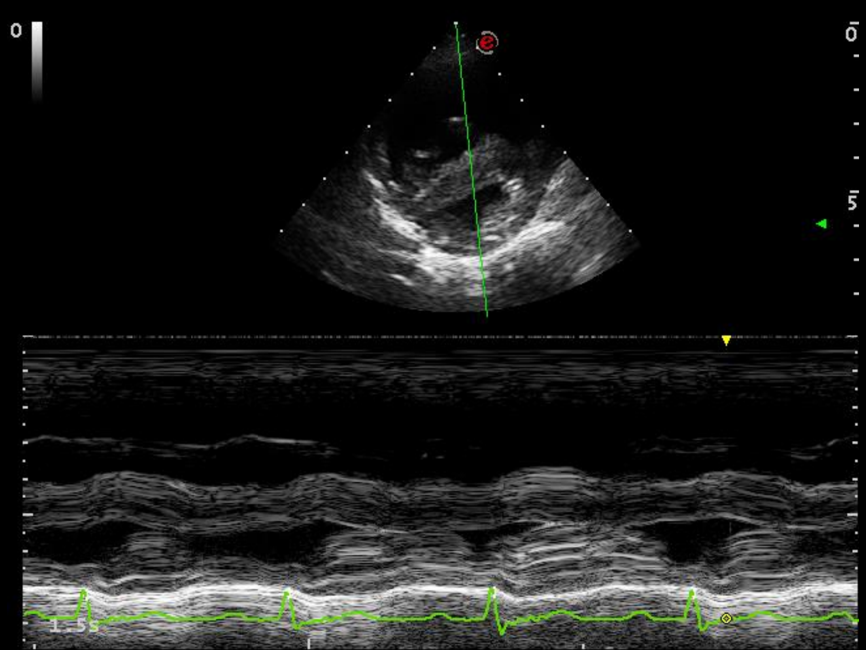
- Mainly through the interventricular septum.
- The pericardium it is mostly relevant for diastolic ventricular interdependence.
- Approximately 20% to 40% of RV systolic pressure and volume outflow results from LV contraction.
- Moreover, in the presence of scarring of the RV or replacement with a non contractile patch, the septum is able to maintain circulatory stability **as long as the RV is not dilated.**
- Beyond the physiological range, excessive RV volume loading can compress the LV and global ventricular function.

VENTRICULAR INTERDIPENDENCE

Volume overload



Pressure overload

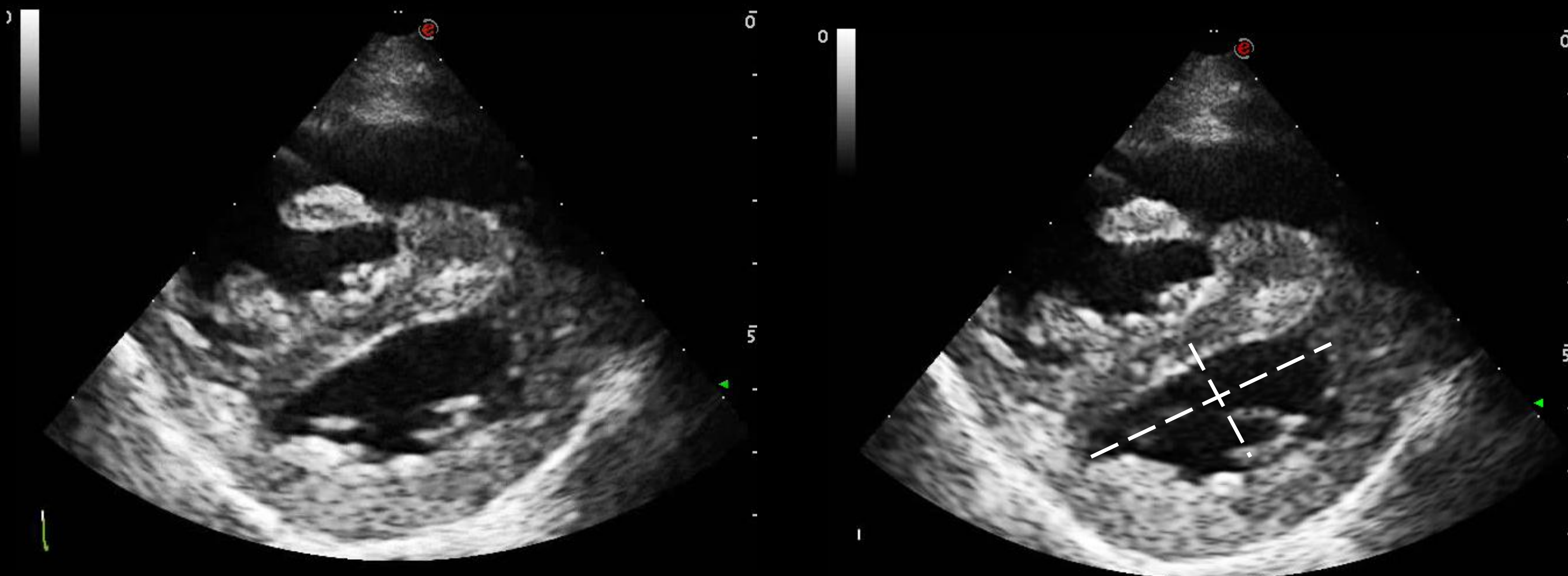


Reversed Bernheim effect

VENTRICULAR INTERDIPENDENCE

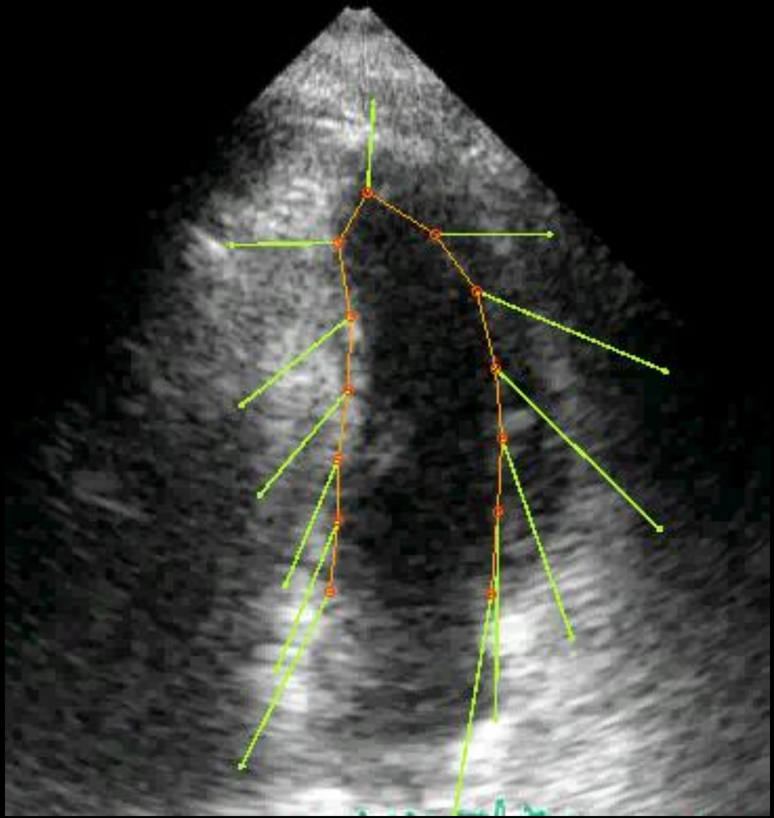
Bilateral Diameter/anteroposterior diameter

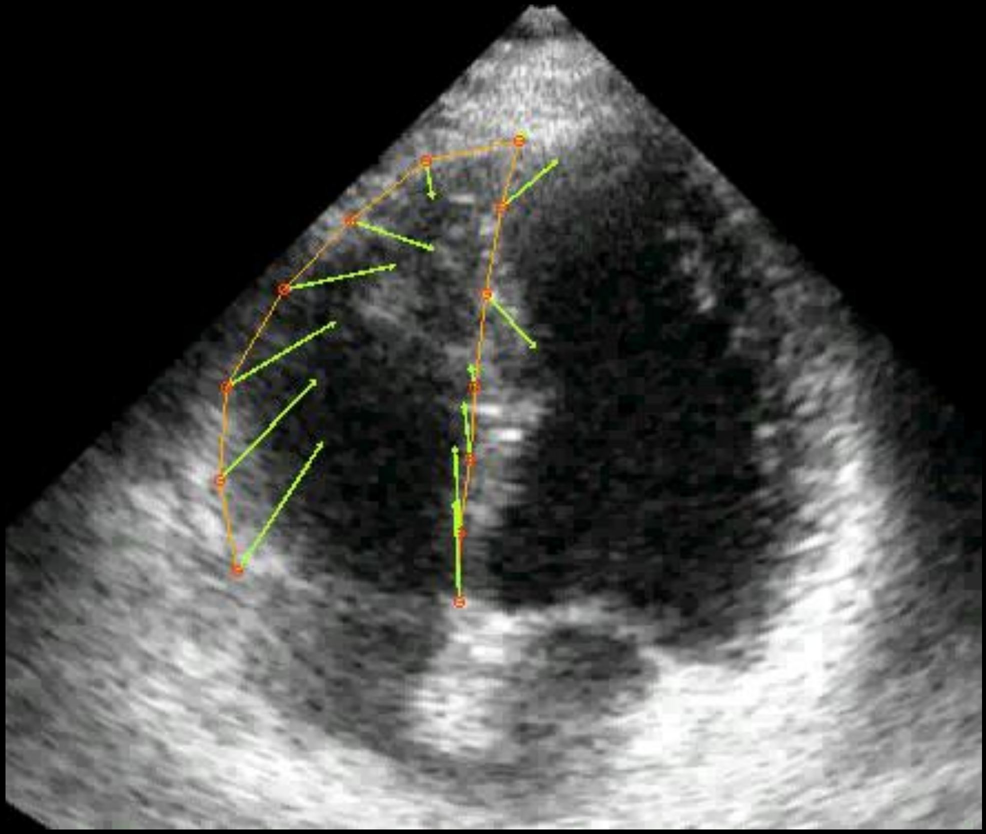
- 1 pressure and/or Volume overload



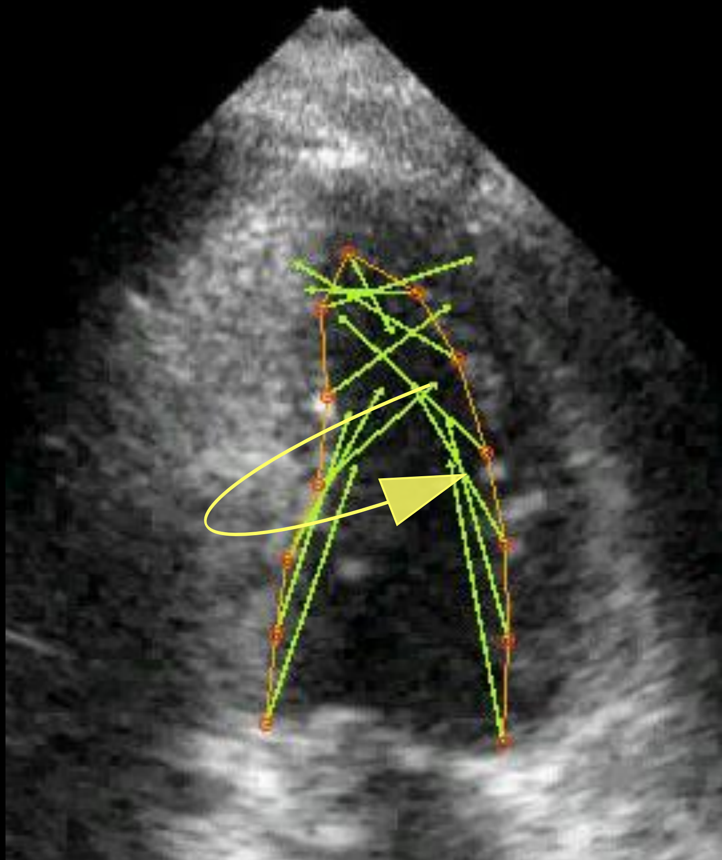
Normal: 1 both end-systole and end-diastole
RV volume overload: +/- 1.0 at end-systole, >1.0 at end-diastole
RV pressure overload: >1.0 at both end-systole and end-diastole

RV PHISIOLOGY OF THE CONTRACTION

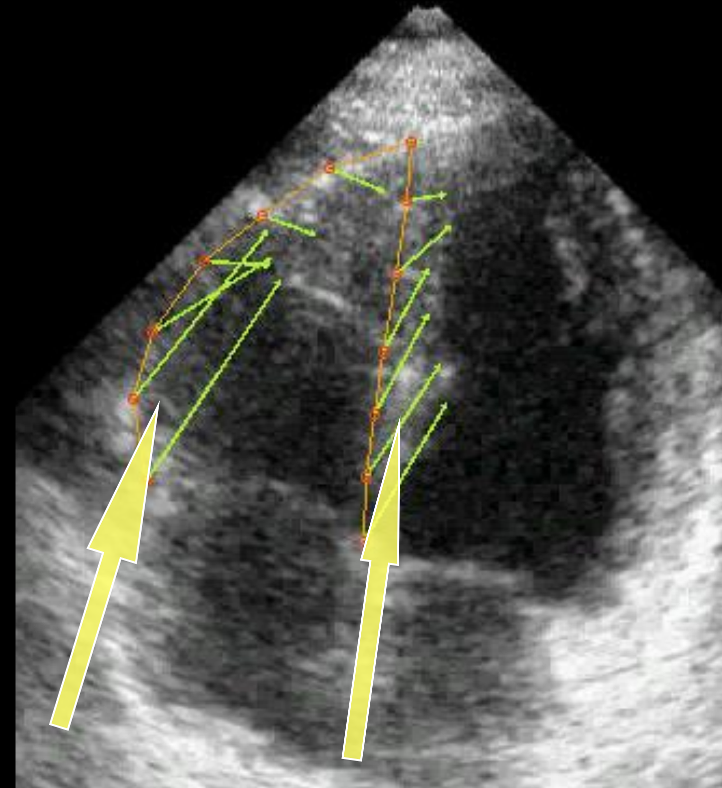




RV PHISIOLOGY OF THE CONTRACTION



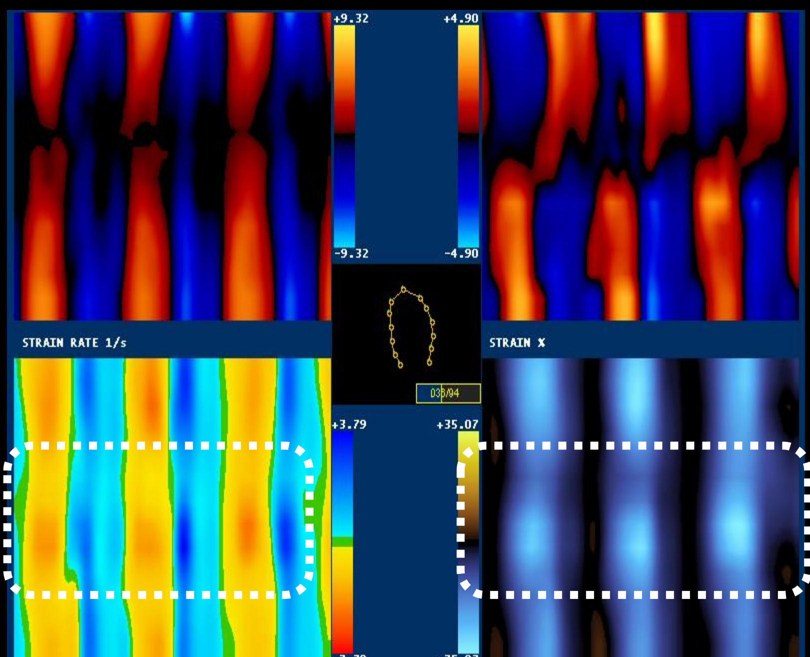
LV Systole



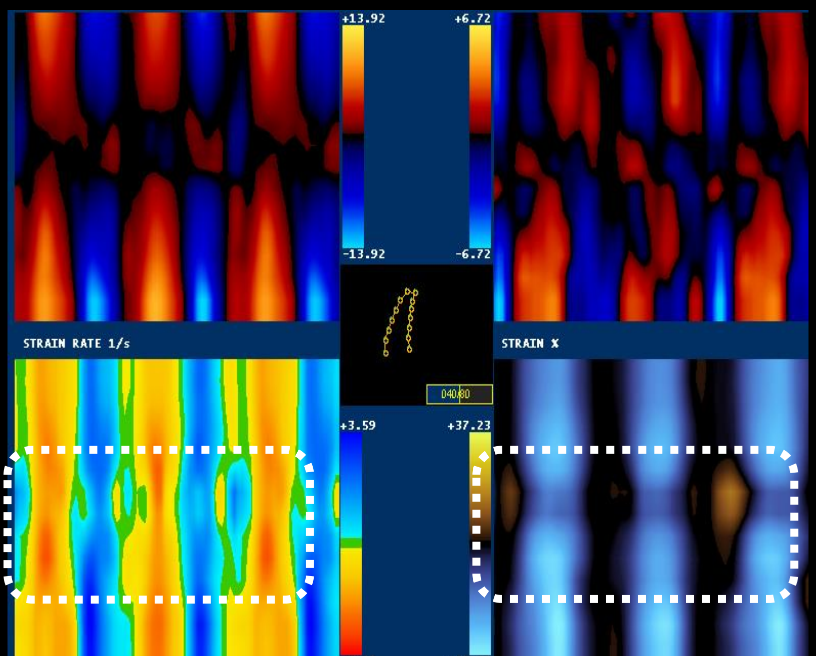
RV Systole

XSTRAIN AND NORMAL RIGHT AND LEFT VENTRICLE COLOR MAP

Normal Left Ventricle



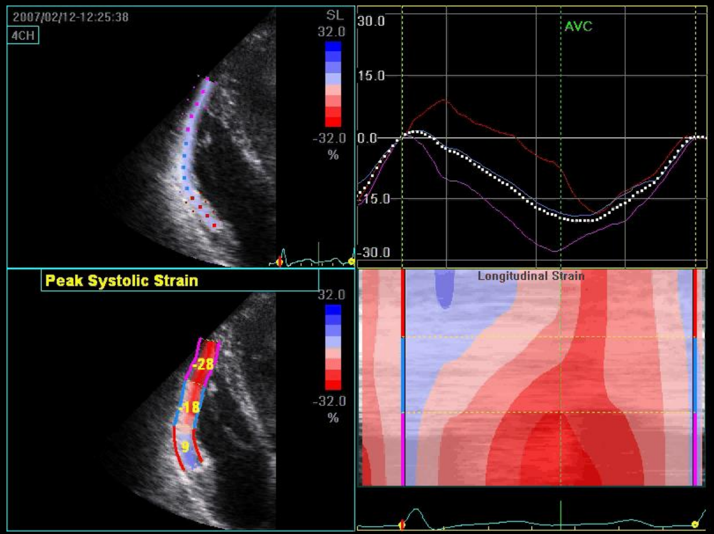
Normal Right Ventricle



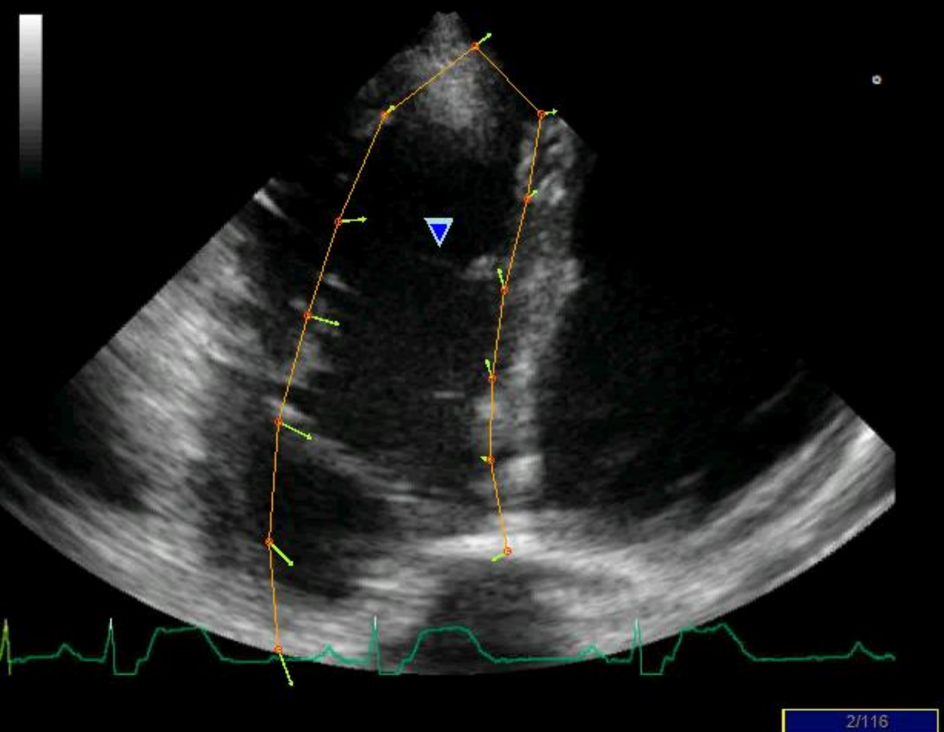
RV REFERENCE VALUES

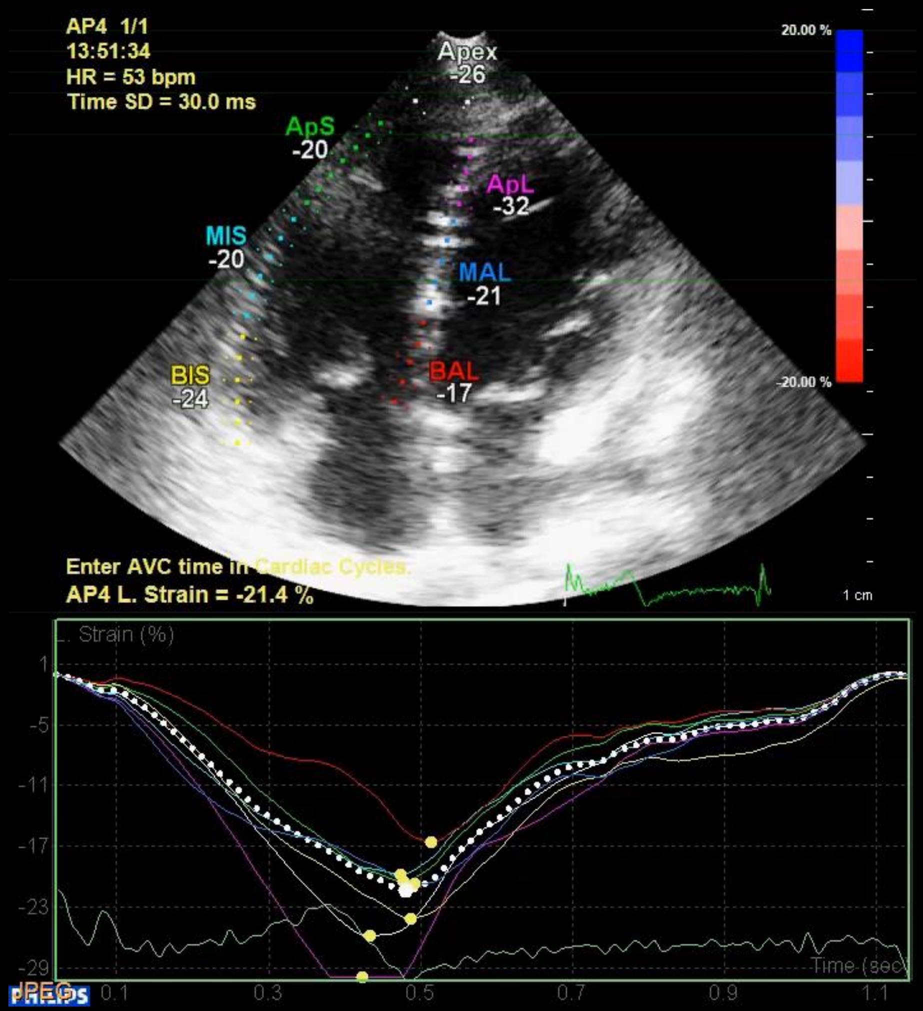
RV ENDO STRAIN (%)						
BAS LAT	MID LAT	APIC LAT	APIC SEP	MID SEP	BAS SEP	Global
-25.12	-21.58	-16.00	-18.24	-19.25	-21.33	-20.77

RV ENDO STRAIN RATE s-1						
BAS LAT	MID LAT	APIC LAT	APIC SEP	MID SEP	BAS SEP	Global
-2.00	-1.62	-1.08	-1.17	-1.40	-1.42	-1.47

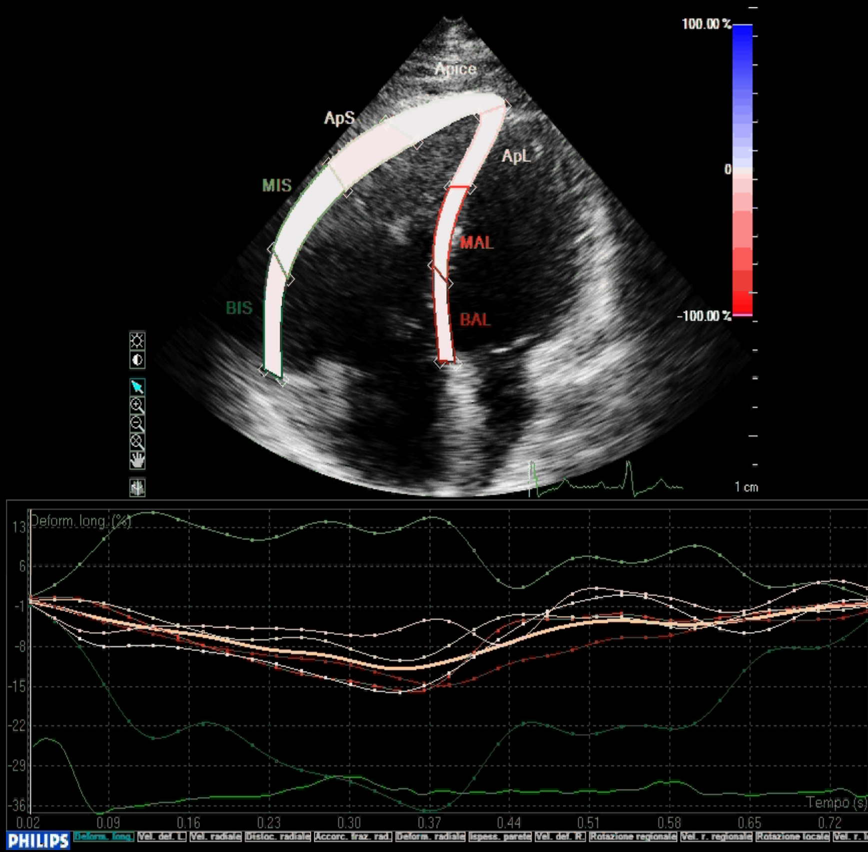


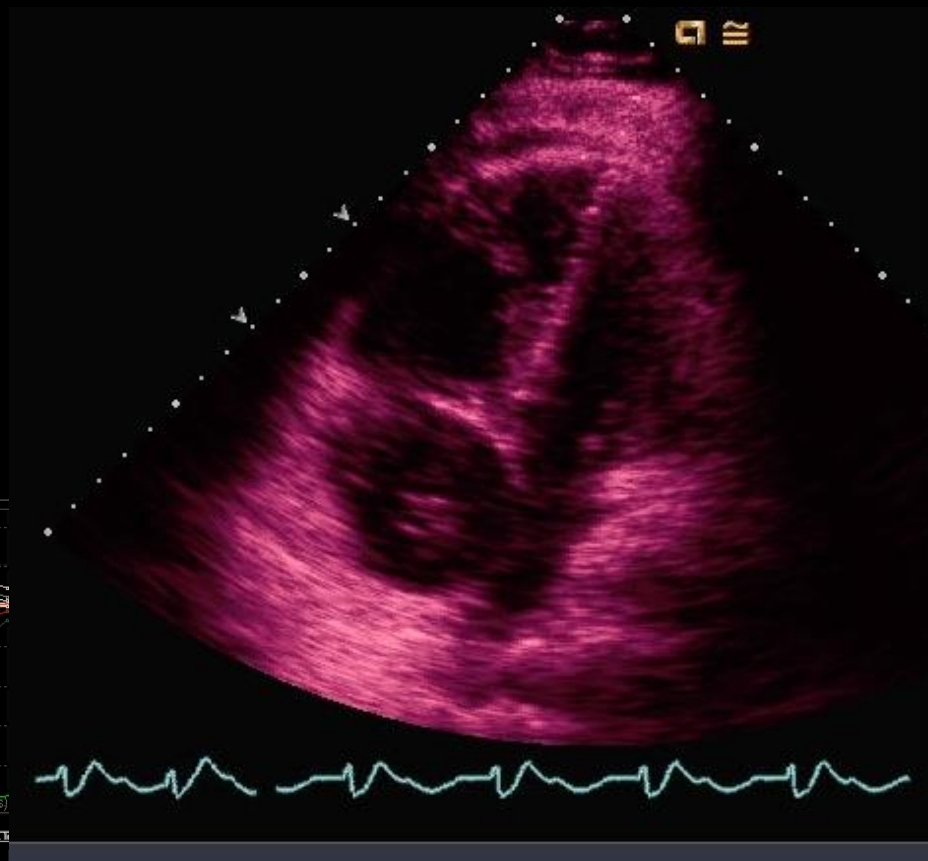
RIGHT VENTRICULAR STRAIN





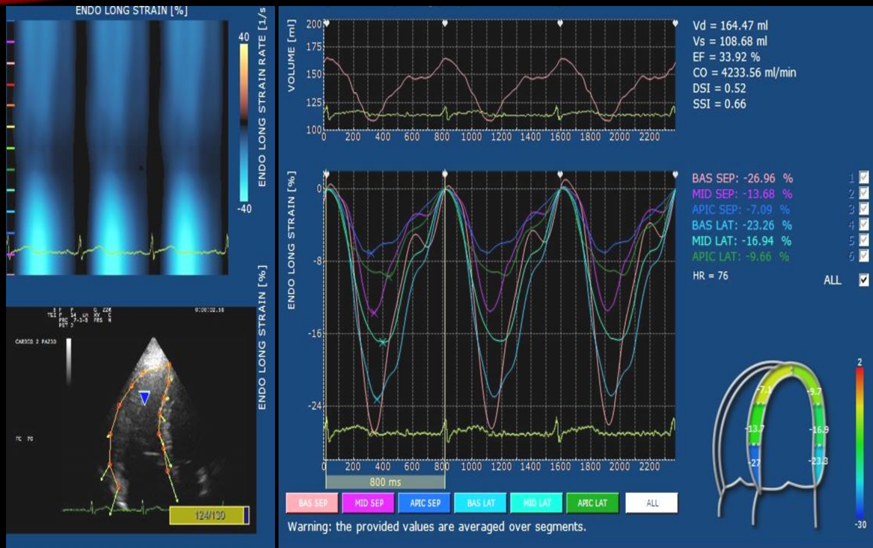
McConnell's Sign

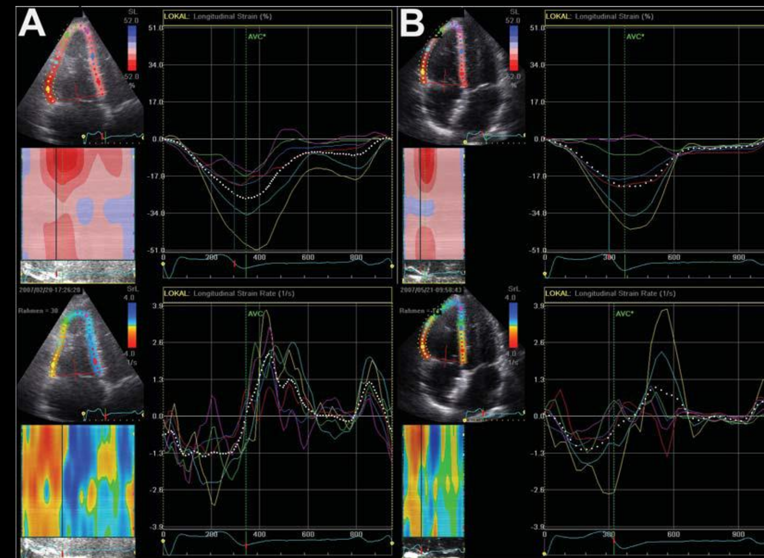




Walsh BM, Moore CL. Mcconnell's sign is not specific for pulmonary embolism: Case report and review of the literature. *J Emerg Med*. 2015;49:301-304

RV Change in ASD Closure





26 patients (16F; 10M) mean age 31 +/- 24.6 years, **<u>In ASD patient RV Strain was significantly higher than in the control group. 24 h. after closure, there was a significant reduction in longitudinal Strain in the RV free wall and the right side of the septum.</u>**

Bussadori et al. Assessment of right and left ventricular longitudinal, circumferential and radial strain and strain rate after atrial septal defect closure through a new 2D echocardiographic based method. ESC 2009

33 patients
20 F, 13 M, mean age 44.7+/-18.5
6 M post closure. **<u>Before percutaneous closure, mean GLS was significantly increased in comparison to control group, and significantly reduced after closure.</u>** Analysis of regional PSS showed significant decrease in the lateral apical, lateral mid, and septal apical segments.

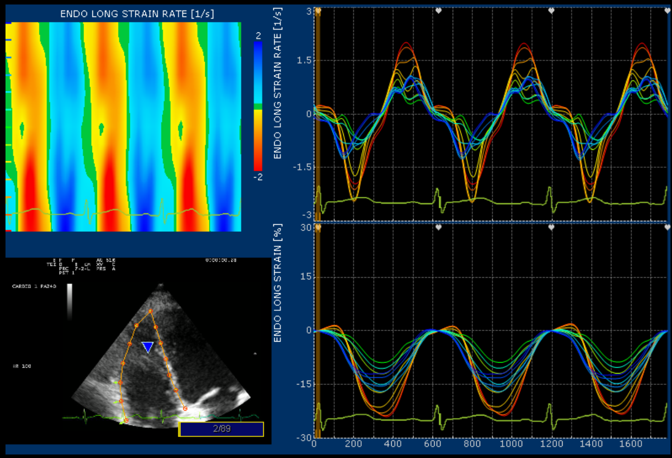
Jategaonkar, S. et al Two-dimensional strain and strain rate imaging of the right ventricle in adult patients before and after percutaneous closure of atrial septal defects European Journal of Echocardiography (2009) 10, 499–502

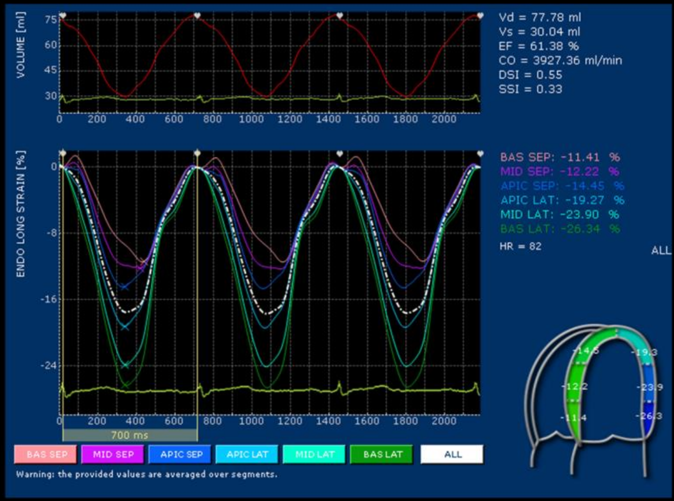
RV CHANGE IN ASD CLOSURE

	Controls	ASD	
Global RV Strain	-20.77±3.87	-23.95±5.24	P = 0,0438

	ASD pre ASDO	24 h after ASDO	
Global RV Strain	-23.95±5.24	-17.04±5.94	0.00016

	ASD pre ASDO	ASD post ASDO	
Basal Circ. Strain	-20.31±4.64	-25.39±5.22	0.00003

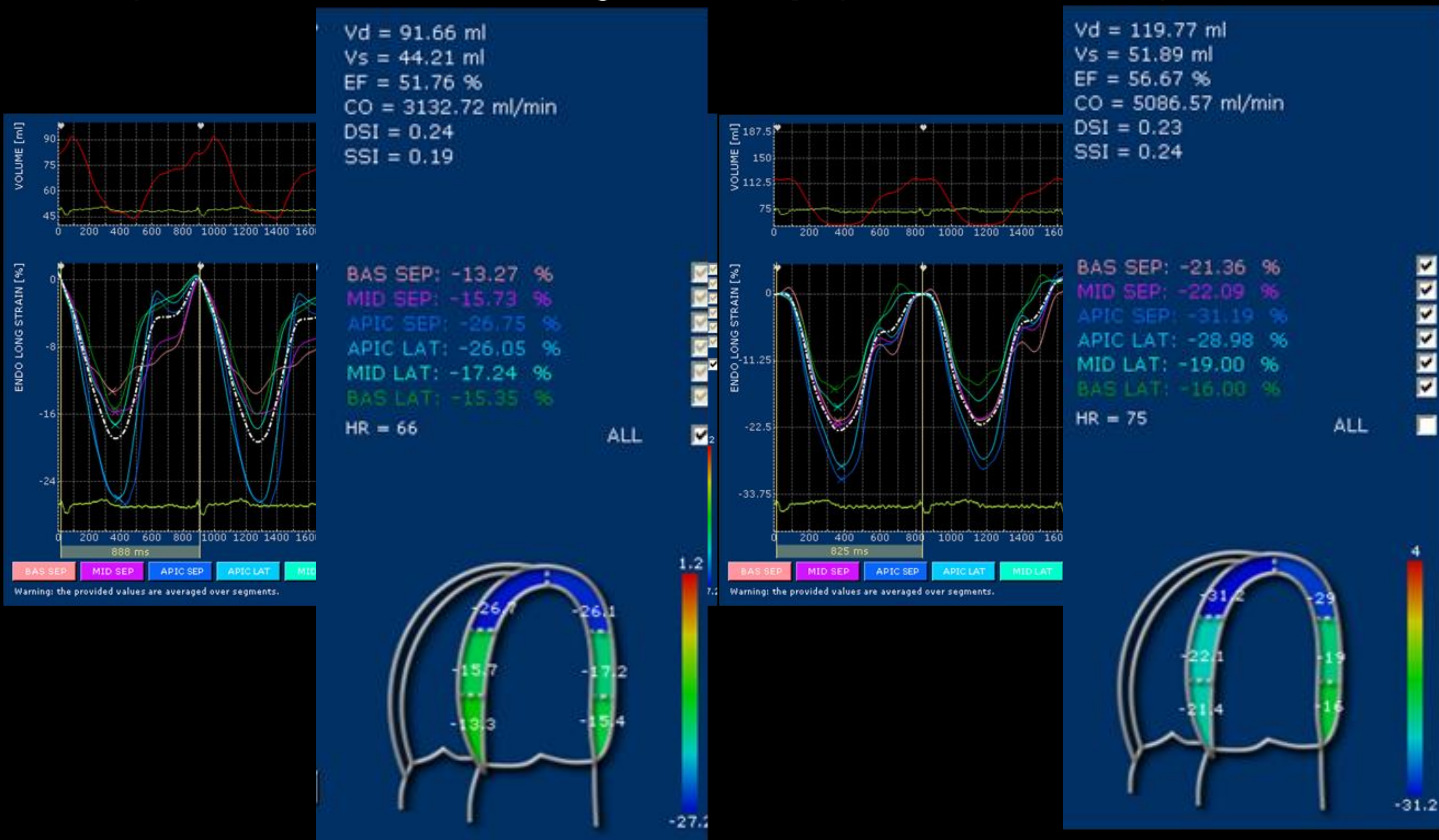




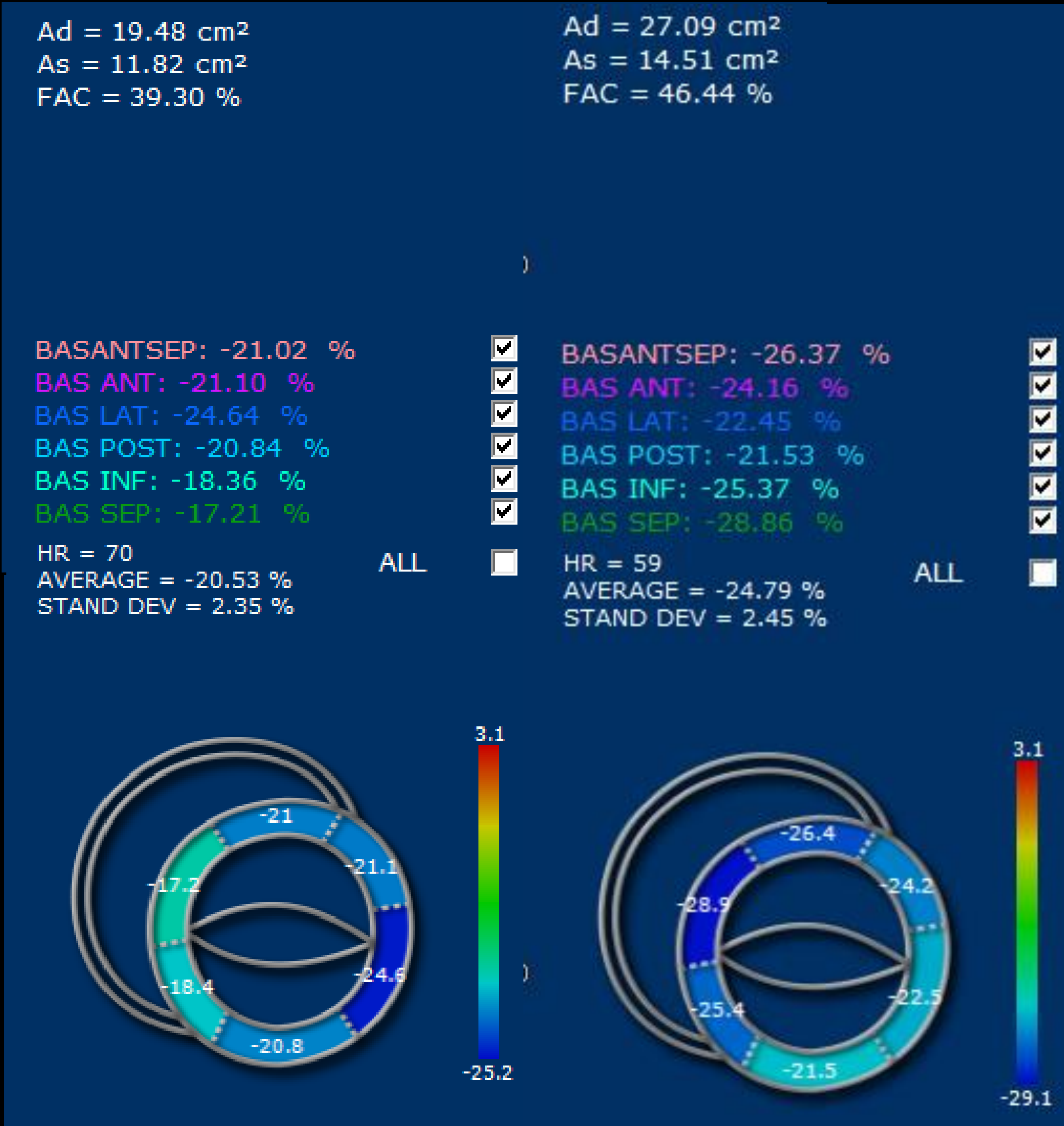
Bussadori C, et al. Right and left ventricular strain and strain rate in young adults before and after percutaneous atrial septal defect closure. *Echocardiography*. 2011;28:730-737

LV CHANGE IN ASD CLOSURE

Left ventricular end diastolic volume and left ventricular cardiac output both increased **significantly** p = 0.002, and p=0.01.

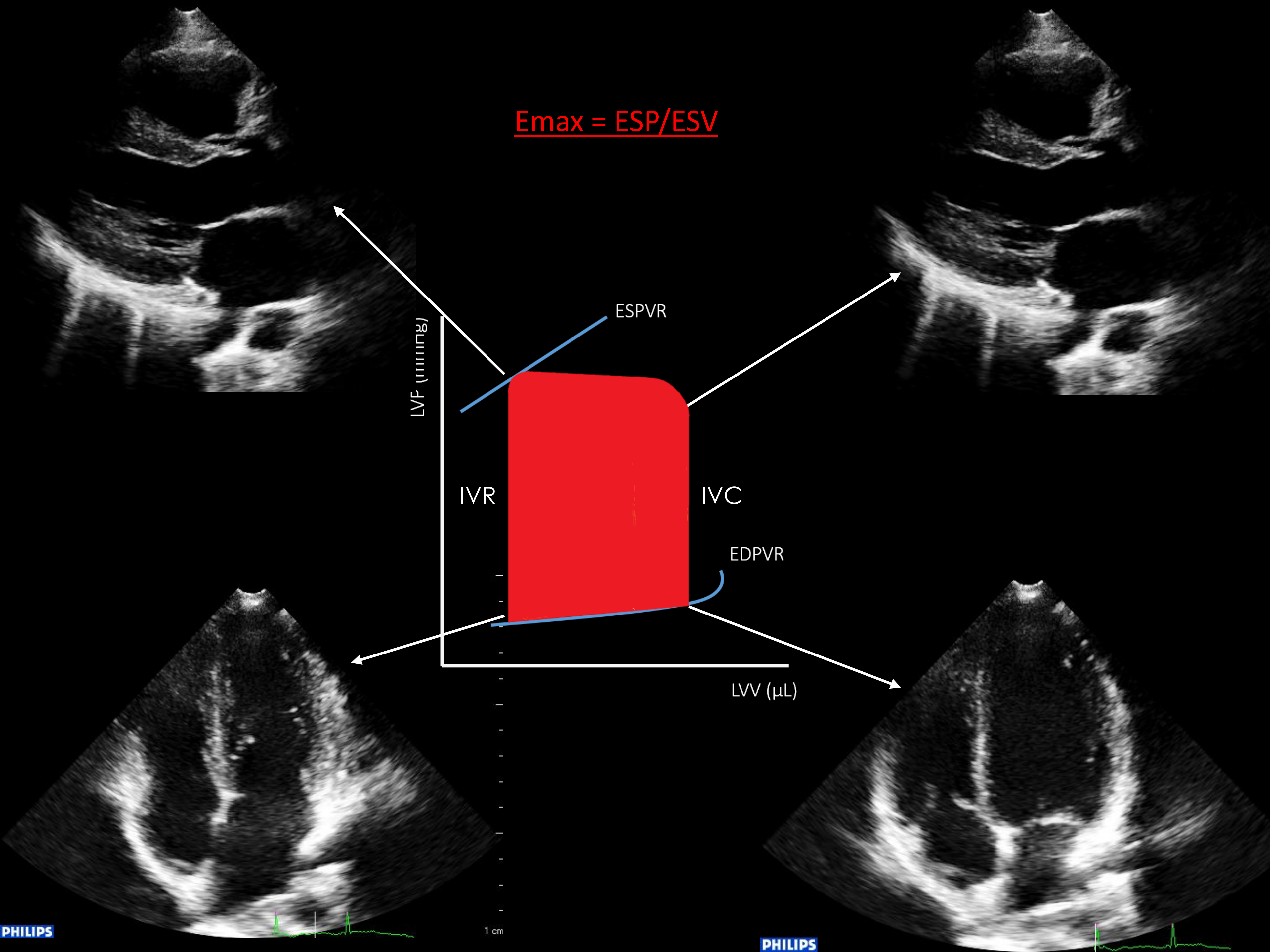


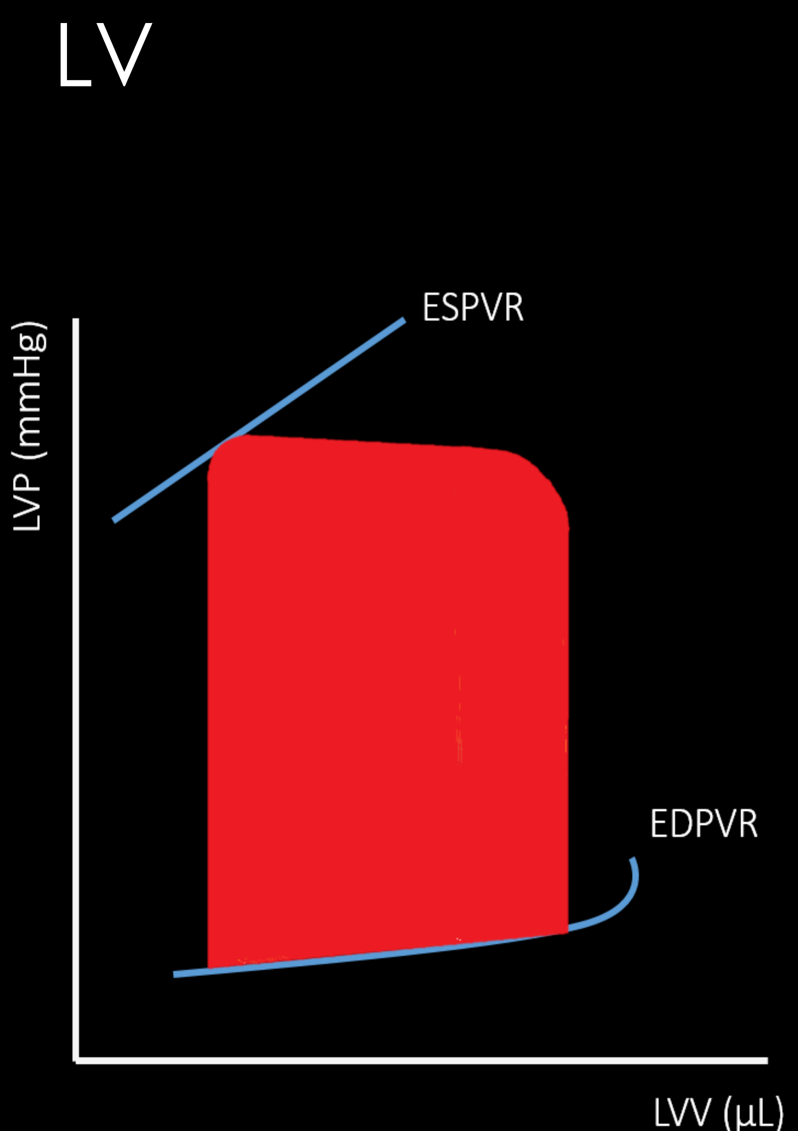
Bussadori C, et al. *Echocardiography*. 2011;28:730-737



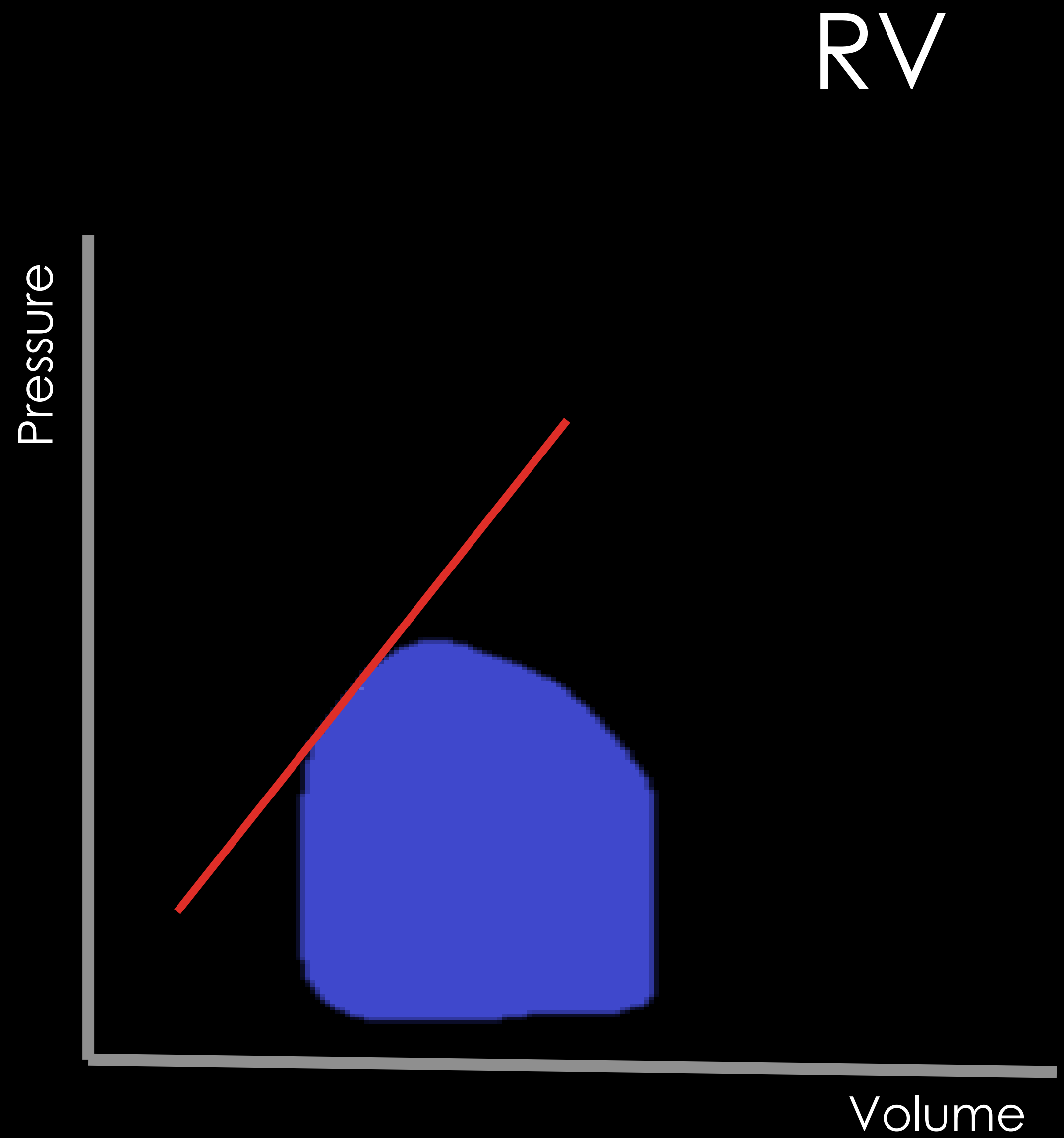
CHANGE IN
CLOSURE

al
mferential
at mitral
augmented
cantly -20.3%
vs -25.39 % ±
= 0.00003.


Emax = ESP/ESV
ESPVR
LVP
IVR
IVC
EDPVR
LVV (µL)
PHILIPS
1 cm
PHILIPS



LV
ESPVR
EDPVR
LVP (mmHg)
LVV (µL)



RV
Pressure
Volume

EFFECT OF PRELOAD VARIATION ON SV
(WITH CONSTANT CONTRACTILITY)

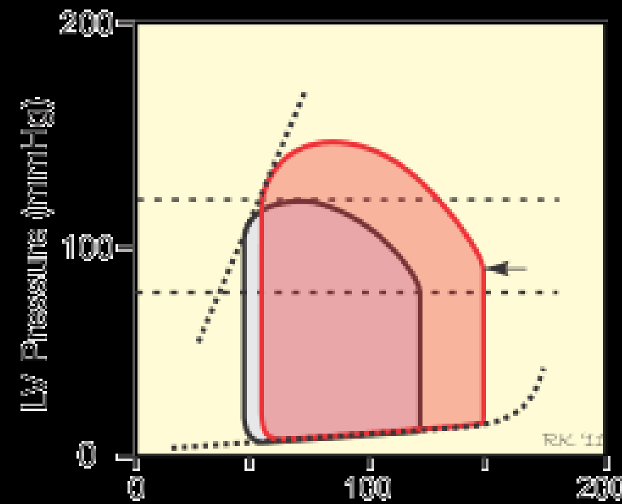
↑ Preload

<u>↑ Stroke Volume</u>

↑ EDV

↑ ESV

= FE



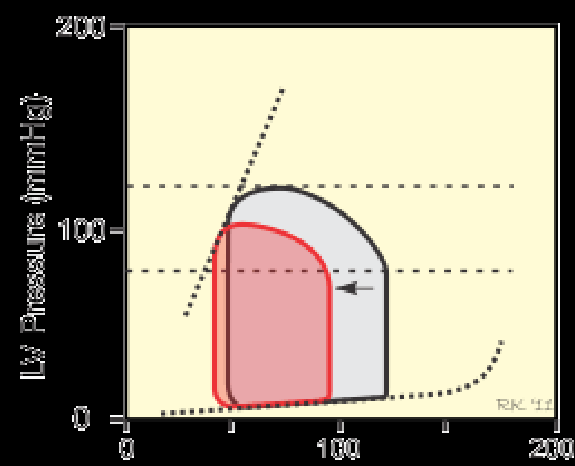
↓ Preload

<u>↓ Stroke Volume</u>

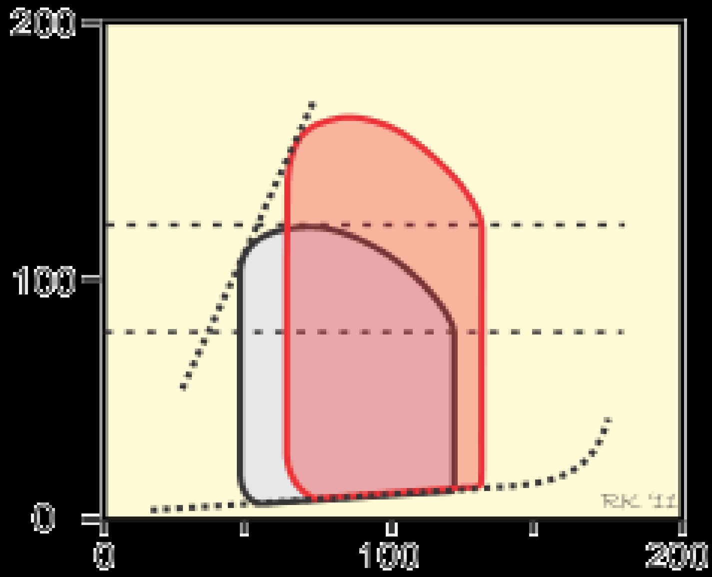
↓ EDV

↓ ESV

= FE



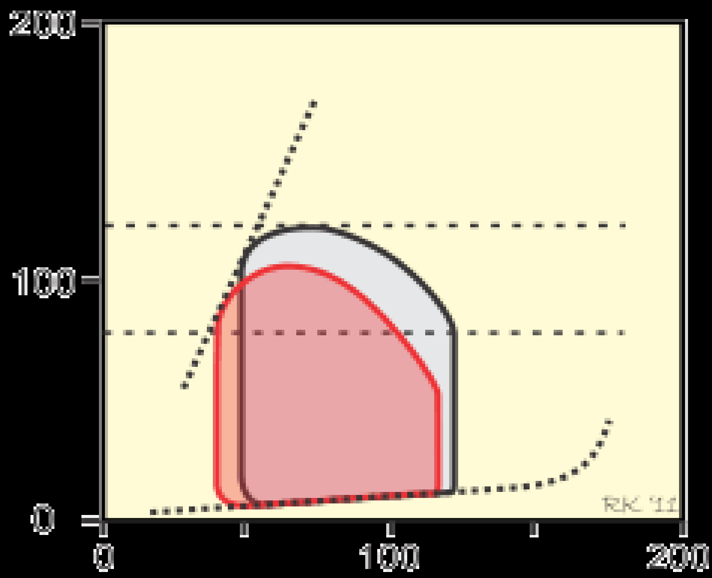
EFFECT OF AFTERLOAD VARIATION ON SV
(WITH CONSTANT CONTRACTILITY)



Increased Afterload

↑EDV ↑ESV

↓SV

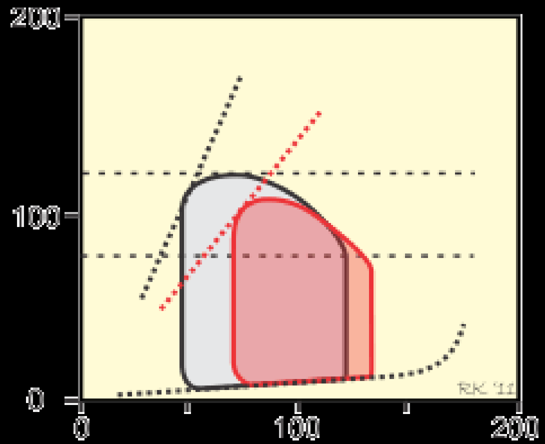


Decreased Afterload:

↓ EDV ↓ ESV

↑ SV

EFFECT OF CONTRACTILITY VARIATIONS

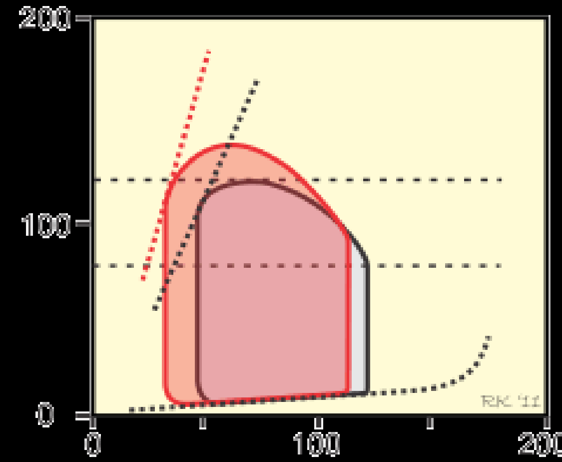


Decreased Contractility:

↓ SV

↑ EDV ↑ ESV

EF ↓



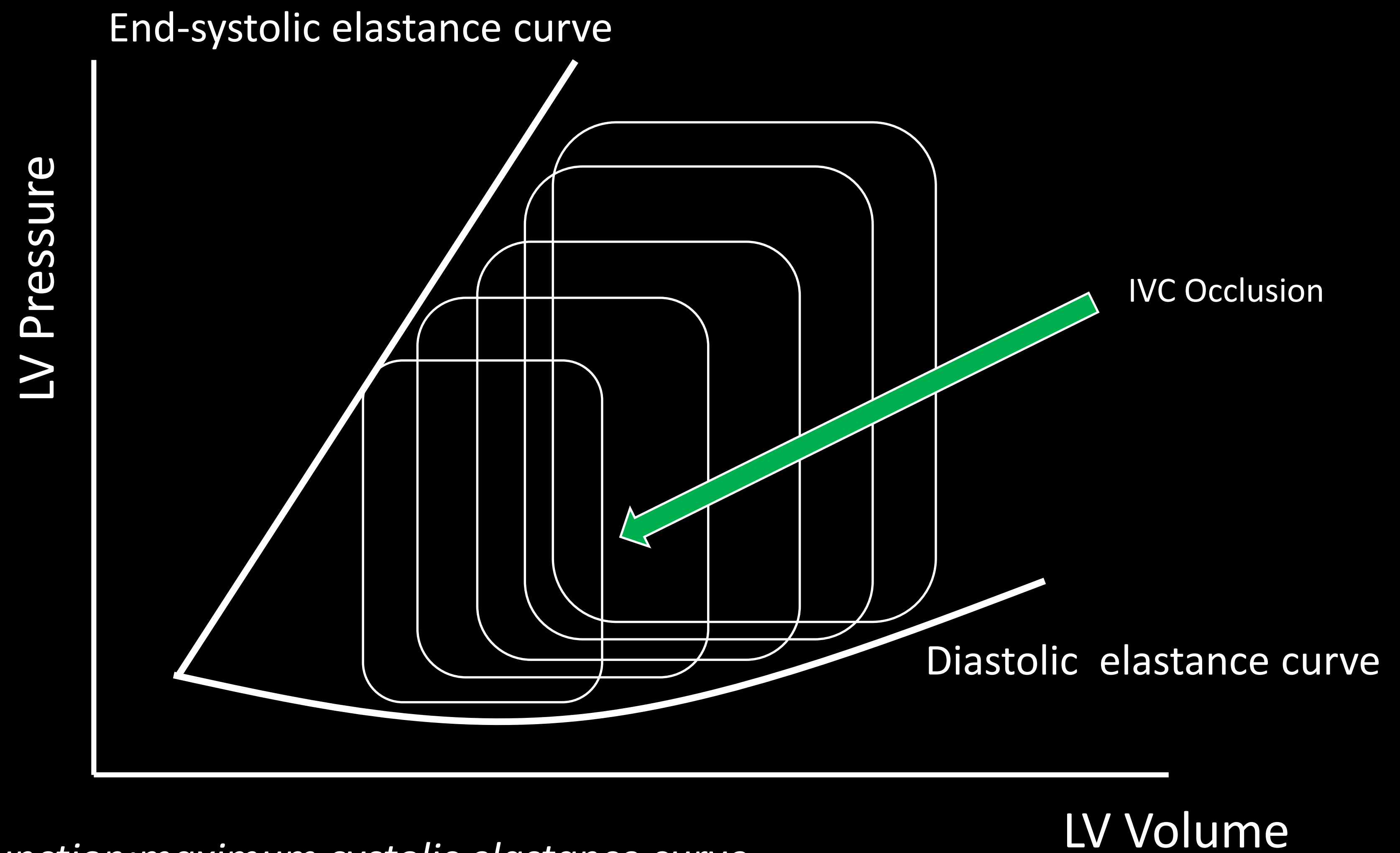
Increased Contractility:

↑SV

↓EDV ↓ESV

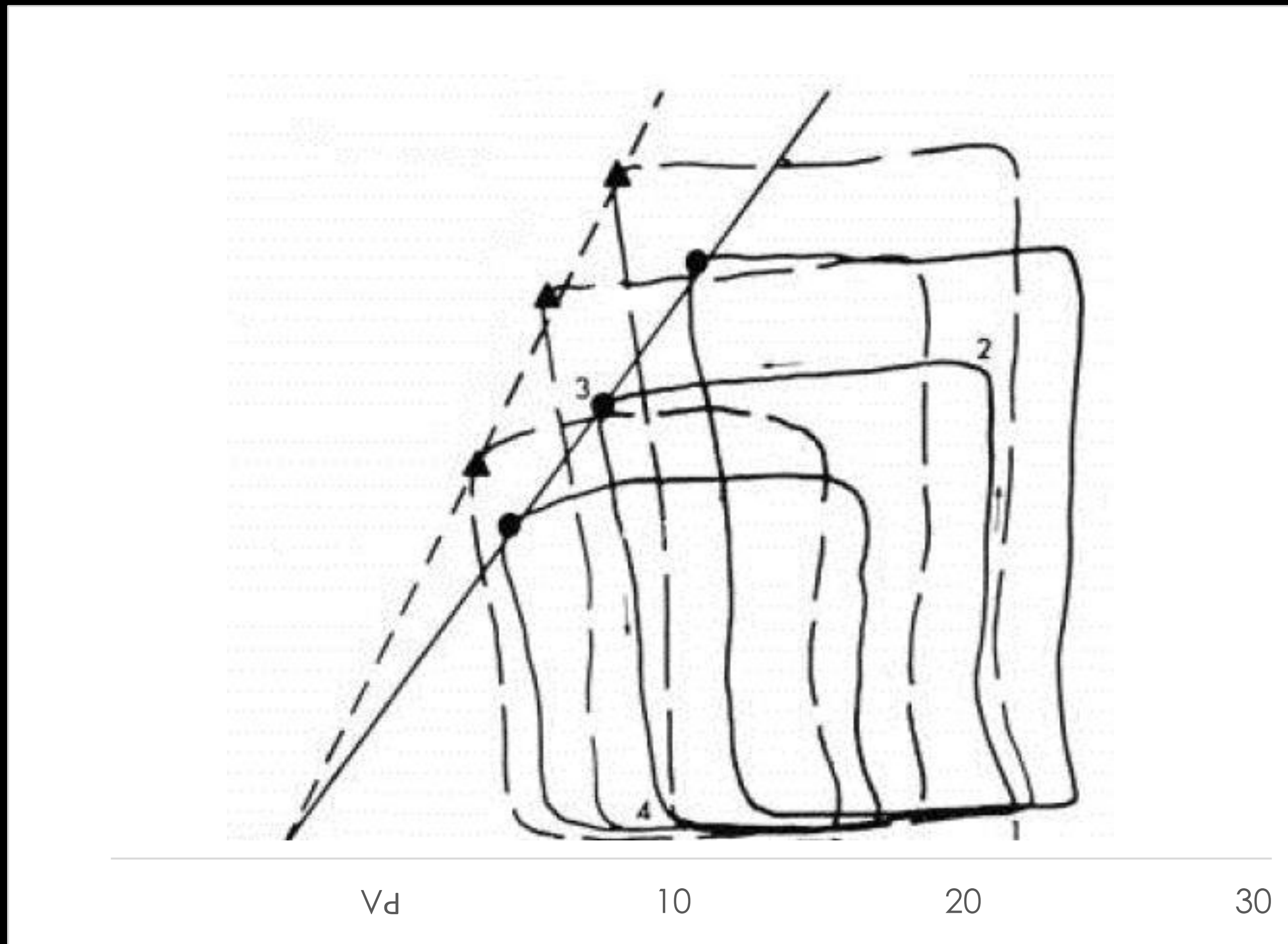
EF ↑

Definition of ventricular function by a family of P-V loops



Systolic function:maximum systolic elastance curve
Diastolic function:diastolic elastance curve

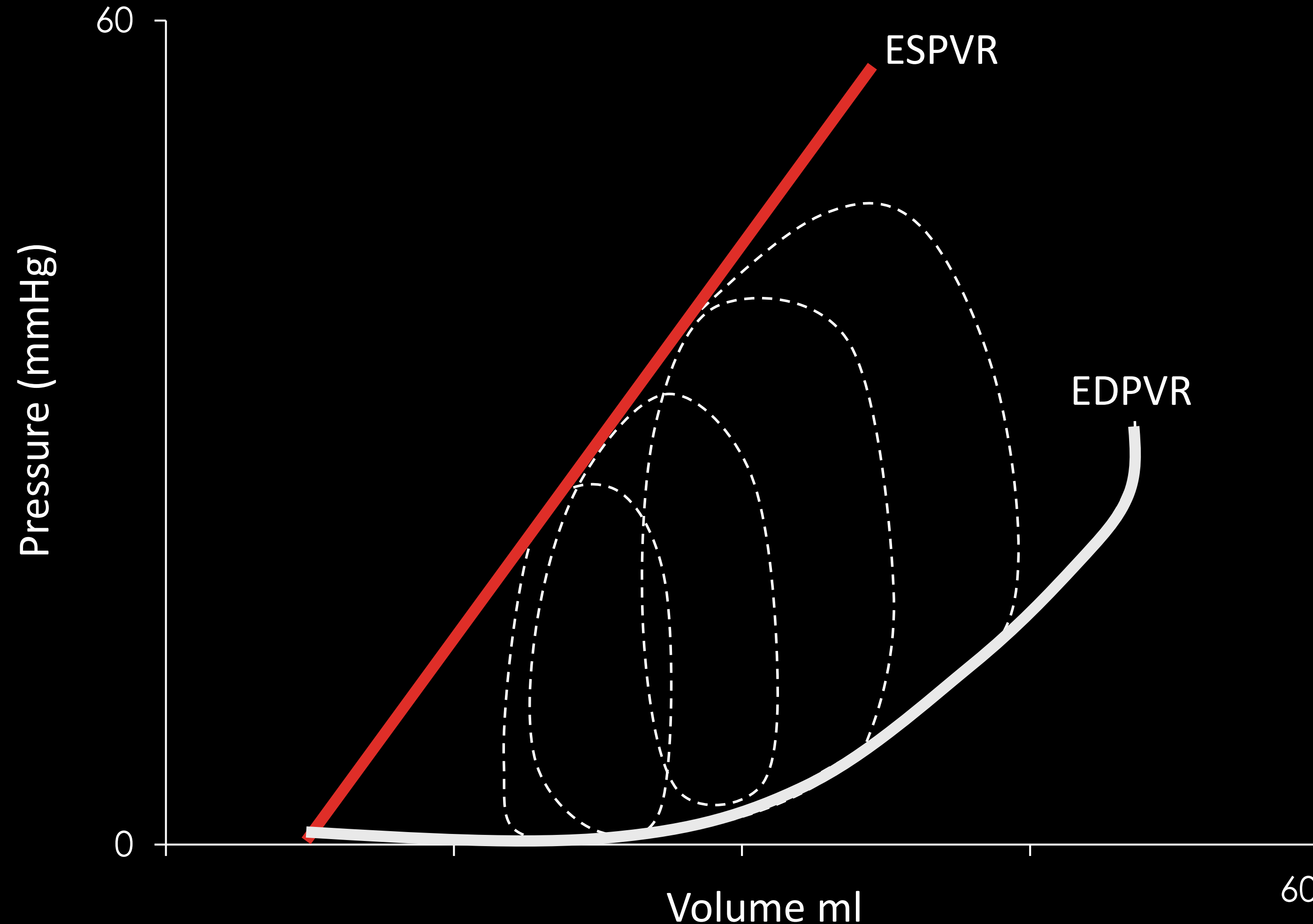
Left ventricular PV loops



Left Ventricular PV loops: rectangular, Emax = end-systole

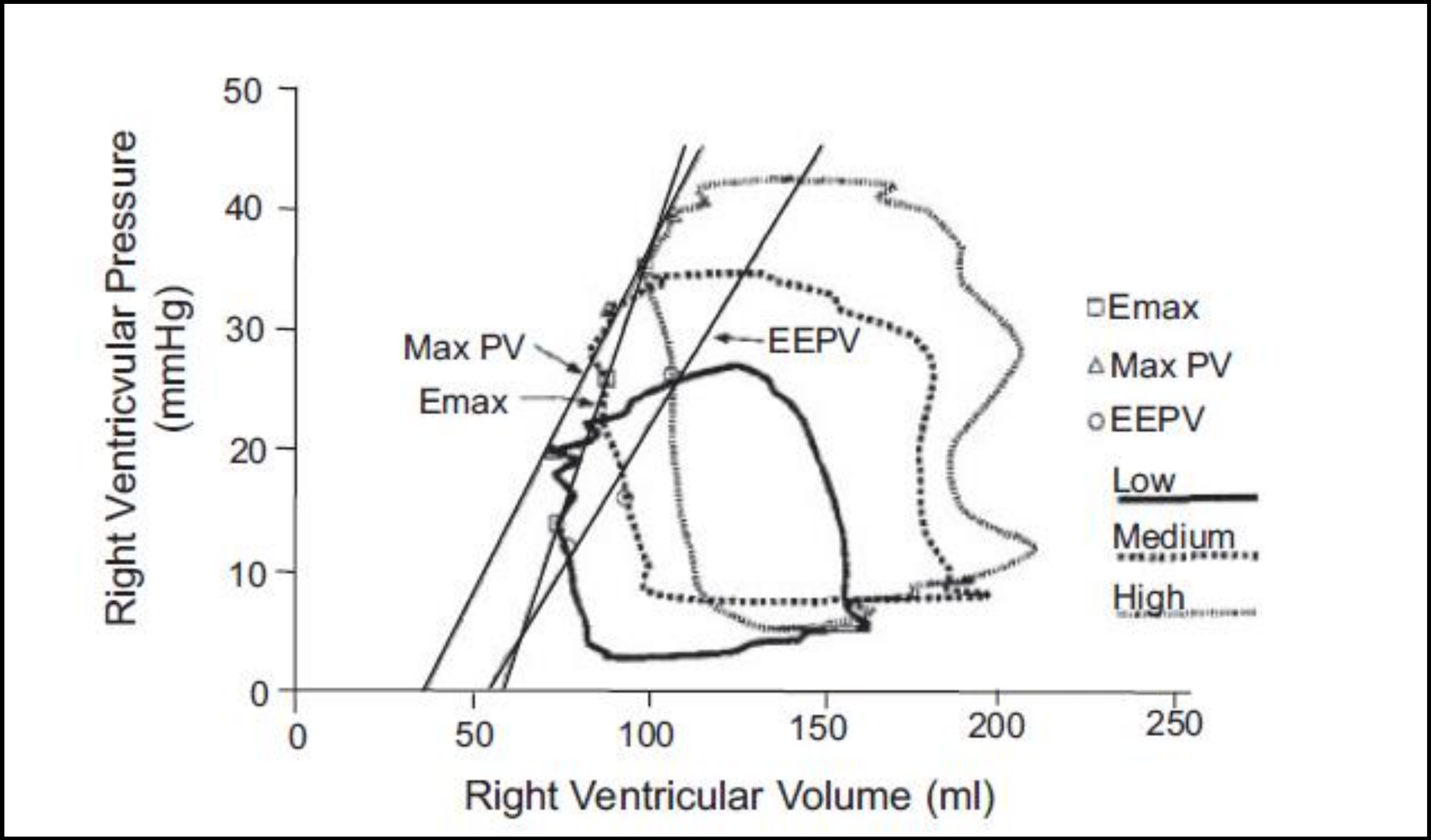
Suga et al, Circ Res 1973; 32:314-322

Right ventricular PV loops at decreasing venous return



Maughan et al. Circ Res 1979; 44:309-15

RIGHT VENTRICULAR PV LOOPS AT INCREASING VENOUS RETURN



ARTERIAL COUPLING

Systolic function: end-systolic elastance: Emax = ESP/ESV

Afterload: arterial elastance Ea

Optimal RV-arterial coupling:

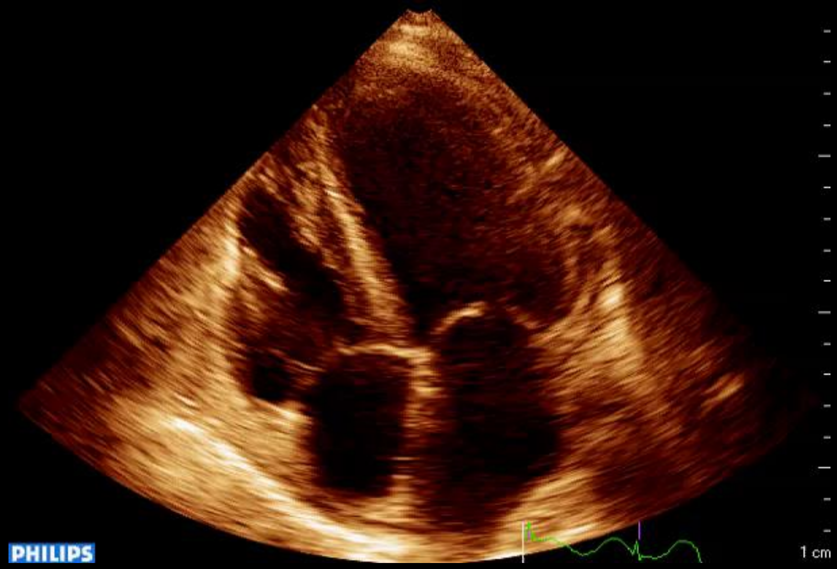
Emax/Ea ratio of 1.5-2

Sagawa et al. Cardiac contraction and the PV relationship,

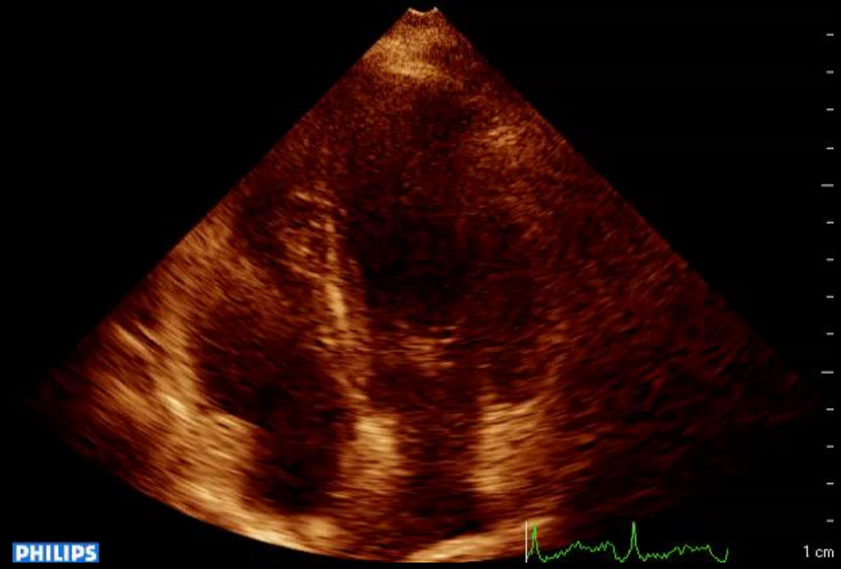
VA COUPLING

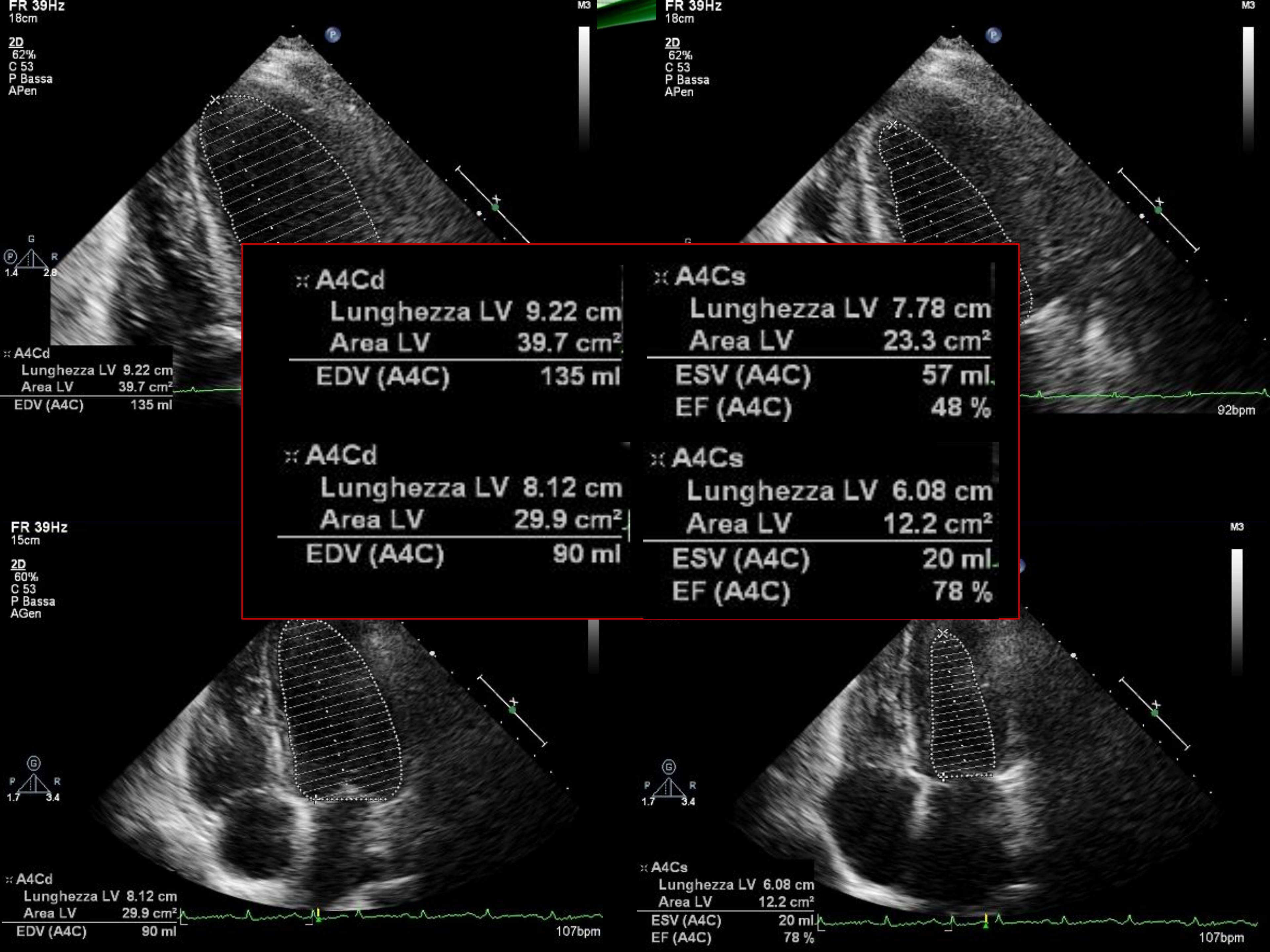
LV Arterial Coupling

Severe HT



After 15 Days of treatment




FR 39Hz
18cm
2D
62%
C 53
P Bassa
APen
A4Cd
Lunghezza LV 9.22 cm
Area LV 39.7 cm²
EDV (A4C) 135 ml
A4Cs
Lunghezza LV 7.78 cm
Area LV 23.3 cm²
ESV (A4C) 57 ml
EF (A4C) 48 %
92bpm
FR 39Hz
15cm
2D
60%
C 53
P Bassa
AGen
A4Cd
Lunghezza LV 8.12 cm
Area LV 29.9 cm²
EDV (A4C) 90 ml
107bpm
A4Cs
Lunghezza LV 6.08 cm
Area LV 12.2 cm²
ESV (A4C) 20 ml
EF (A4C) 78 %
107bpm

RV FUNCTION AND RV REMODELING

- RV remodeling and adaptation to P/V overload is different depending on whether it occurs in early or later life

- In adults, evaluation of RV function needs to take into consideration:
  1. The pathophysiology of the disease
  2. The structural/functional changes caused by the treatment

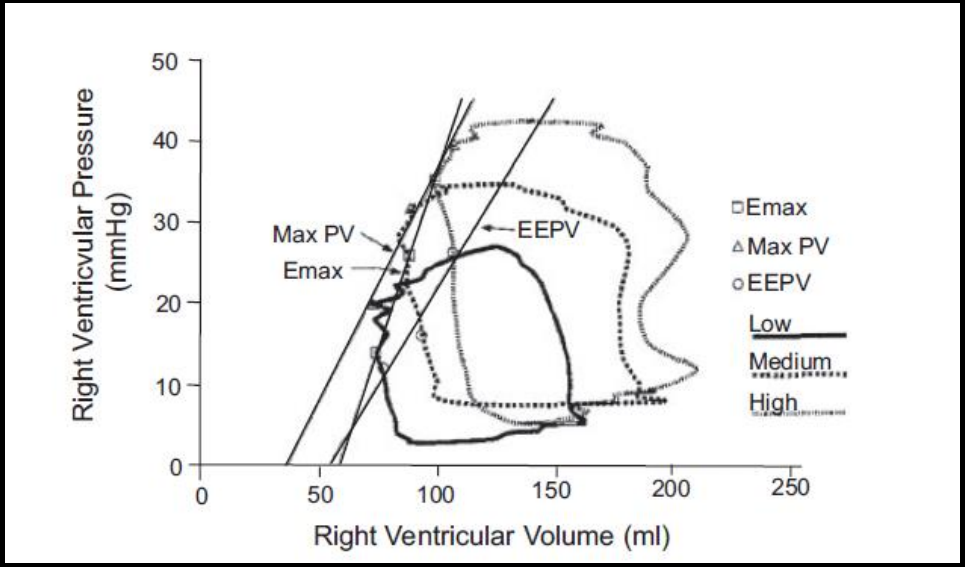
RV FUNCTION AND RV REMODELING

RV has been considered as a chamber more adaptable to volume overload than LV but less able to tolerate pressure overload

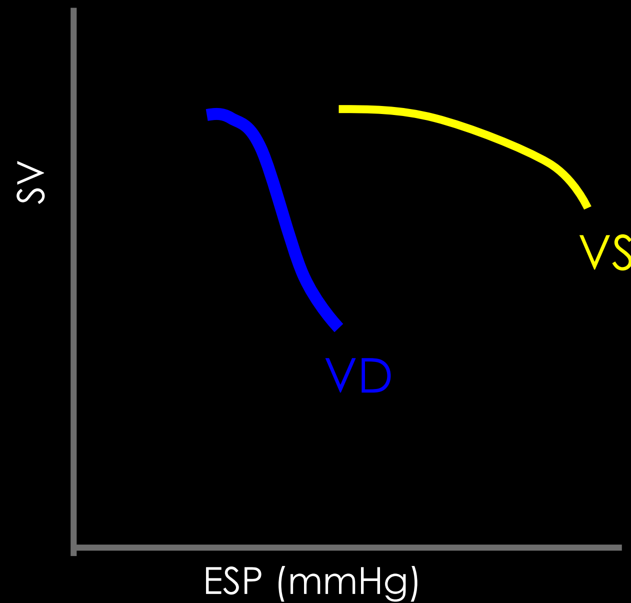
Nevertheless, things are much more complex and the RV can remodel in a wide variety of ways

RIGHT VENTRICLE : VOLUME PUMP …

Increase of Preload



Increase of afterload



VA COUPLING

To Each his own

RV FUNCTION AND RV REMODELING IN PUPPIES

Chronic pressure overload of RV in children results in ↑↑ hypertrophy more than in adult age such as in pulmonary hypertension or pulmonary thromboembolism

DOI: 10.1111/echo.12566

Echocardiography

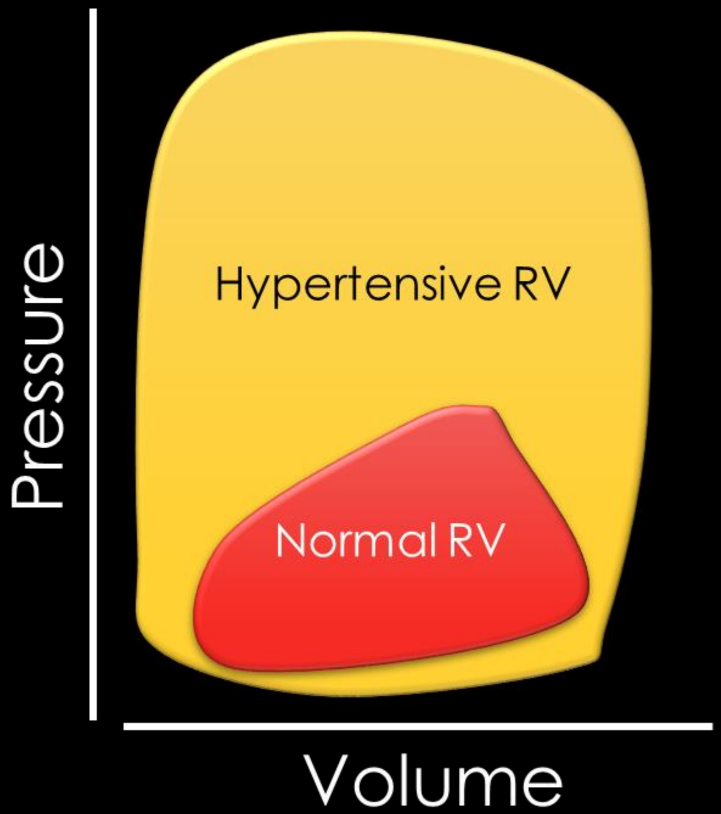
REVIEW ARTICLE

Evaluation of Right Ventricular Function in Adults with Congenital Heart Defects

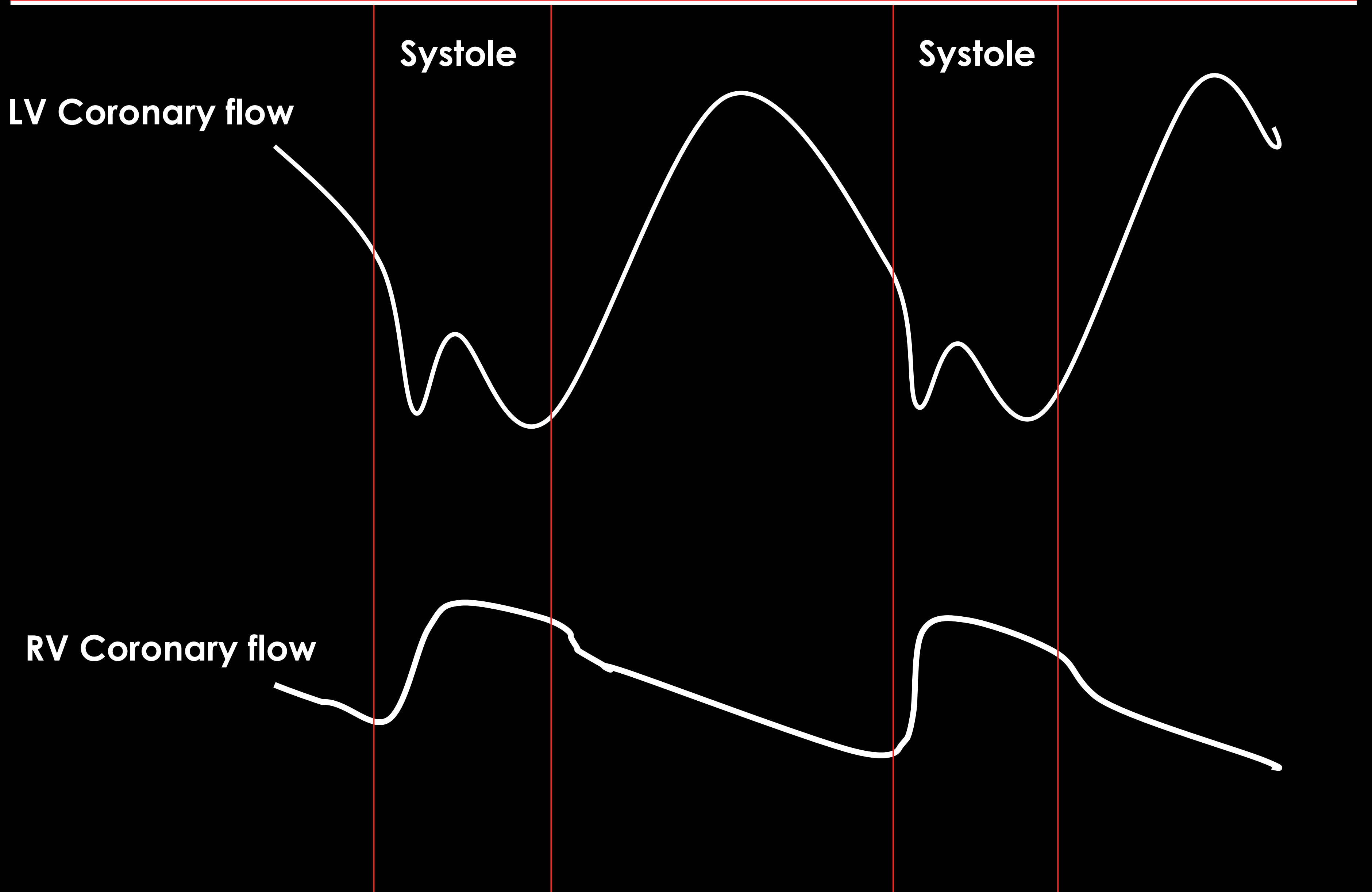
Claudio Bussadori, M.D., Ph.D.,* Giovanni Di Salvo, M.D., Ph.D.,† Francesca R. Pluchinotta, M.D.,*
Luciane Piazza, M.D.,* Giampiero Gaio, M.D.,‡ Maria Giovanna Russo, M.D.,‡ and
Mario Carminati, M.D., F.E.S.C., F.S.C.A.I.*

VENTRICULAR PRESSURE–VOLUME RELATIONSHIPS AND ITS PERFORMANCE

- ❖The afterload reserve of the normal right ventricle is approximately one-third of that of the left ventricle.
- ❖Acute changes in acute pulmonary impedance are poorly tolerated by the right ventricle.
- ❖Slowly and early progressive rise in pulmonary arterial impedance may result in progressive change toward a ‘‘left ventricular’’ pattern of the pressure–volume loop.

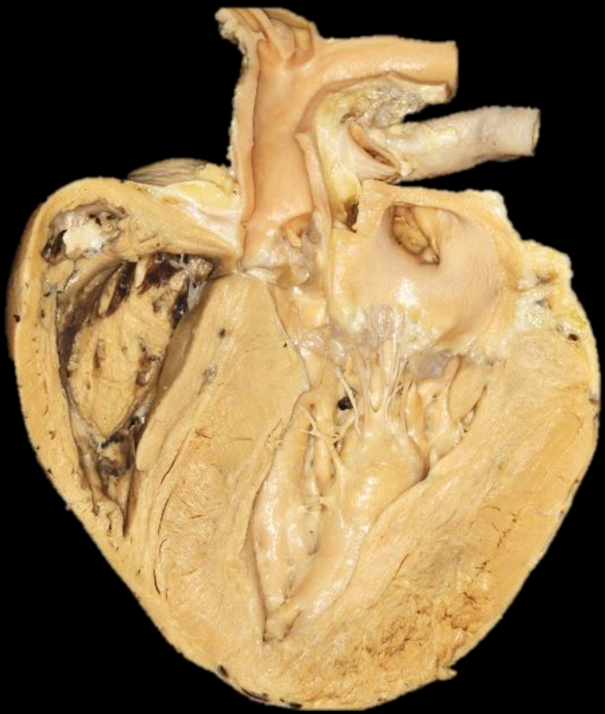


Coronary flow in the lower-pressure right ventricle occurs mostly in systole



RIGHT VENTRICULAR FIBERS ORIENTATION AND REMODELING

Normal



Normal

RV REMODELING IN PRESSURE OVERLOAD: ACQUIRED VS CONGENITAL

Pulmonary Thromboembolism

Eisenmenger

RIGHT VENTRICULAR REMODELING

Pulmonary Hypertension (PTH)

Inadequate hypertrophy
Acquired pressure overload

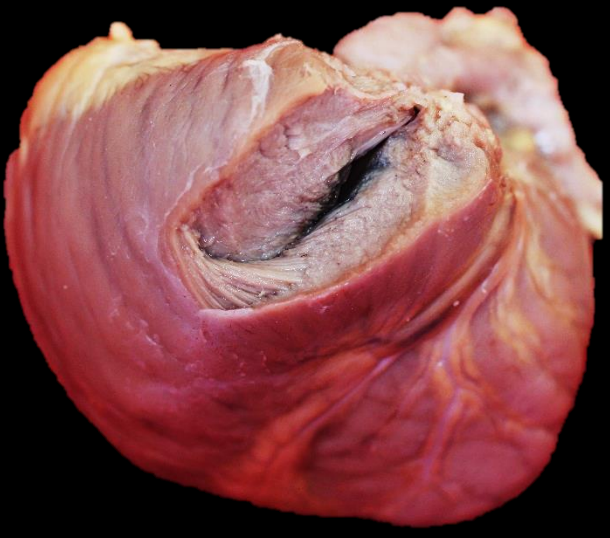
Tricuspid dysplasia

Volume overload

RIGHT VENTRICULAR FIBERS ORIENTATION AND REMODELING

Human ToF

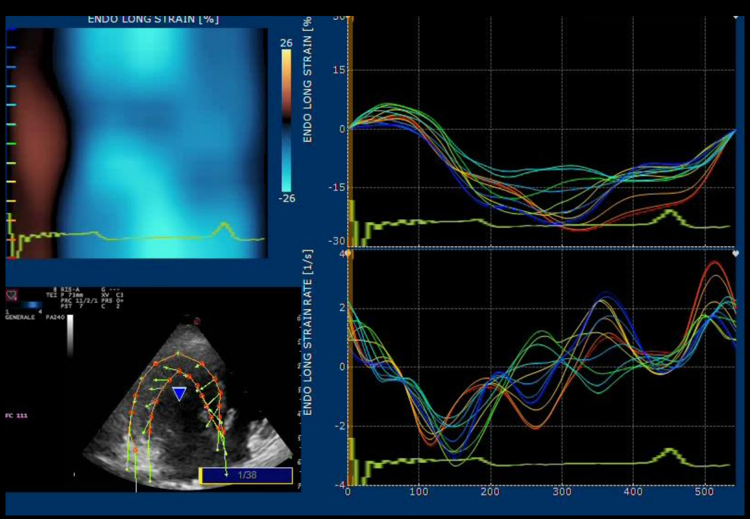
Severe PS

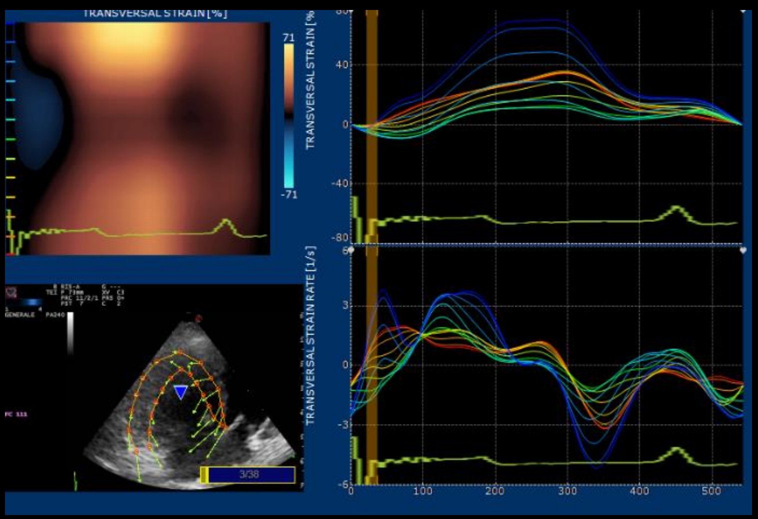


RV RESTRICTIVE PHYSIOLOGY

Gross right ventricular hypertrophy, small RV cavity volumes, and fibrosis.

Systolic function become much more radial than longitudinal.





Bussadori C. Imaging evaluation, . *in: Chessa, M. Giamberti, A. The Right Ventricle in Adults with Tetralogy of Fallot Springer, Milan 2012, pp. 91-112*. 2012

RIGHT VENTRICULAR FIBERS ORIENTATION AND REMODELING

Congenital Chronic pressure overload (PS or Eisenmenger) cause:

- Circumferential fibers hypertrophy.
- Systolic function become much more radial than longitudinal.
- Adaptation to high systolic pressure.
- **Restrictive physiology**.

Bussadori C, Salvo GD, Pluchinotta FR, Piazza L, Gaio G, Russo MG, Carminati M. Evaluation of right ventricular function in adults with congenital heart defects. *Echocardiography*. 2014

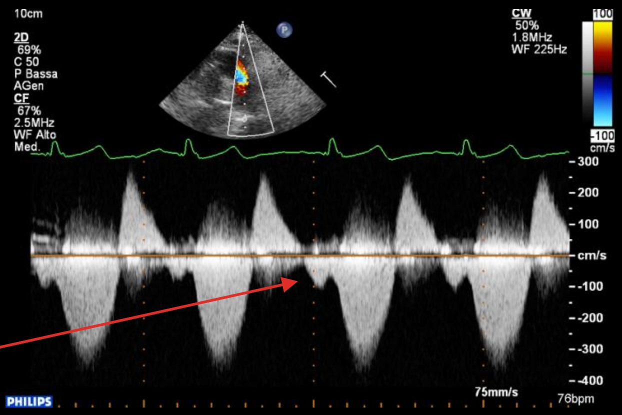
RV RESTRICTIVE PHYSIOLOGY

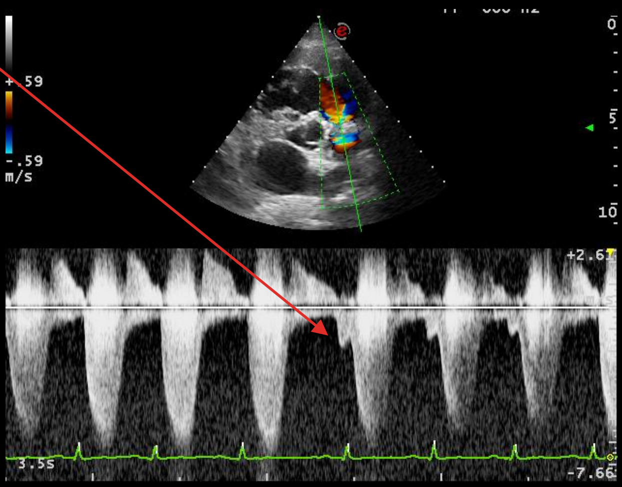
RAP > of PADP

- Transtricuspid flow will be transmitted to the pulmonary artery rather than translating to right ventricular filling.

End Diastolic Forward Flow (EDFF)

- Persistence of antegrade diastolic flow in the pulmonary artery.





Cullen S, et al. Circulation. 1995 Mar 15;91(6):1782–9.
Gatzoulis MA et al Circulation. 1995 Mar 15; 91(6):1775–81.

Different Patterns of Adaptation of the Right Ventricle to Pressure Overload: A Comparison between Pulmonary Hypertension and Pulmonary Stenosis

Ruxandra Jurcut, MD, PhD, Sorin Giusca, MD, Razvan Ticulescu, MD, Elena Popa, MD, Mihaela-Silvia Amzulescu, MD, Ioana Ghiorghiu, MD, PhD, Ioan Mircea Coman, MD, PhD, Bogdan Alexandru Popescu, MD, PhD, Jens-Uwe Voigt, Prof, MD, PhD, and Carmen Ginghina, Prof, MD, PhD, *Bucharest, Romania; Leuven, Belgium*

- PS
- Eisenmenger,
- Systemic Right Ventricle
- Idiopathic PHT
- Pulmonary Thromboembolism




BIDIMENSIONAL RV1, RV2, RV3 MEASURES

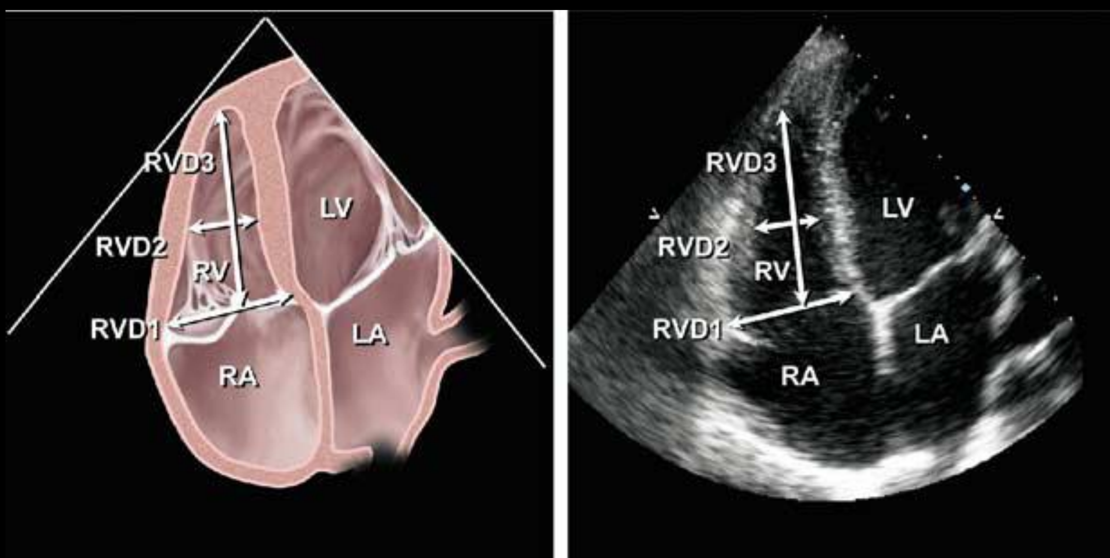
Apical 4 chamber view optimized for the RV:

<u>3 standard Ø</u> (measures in late diastole):

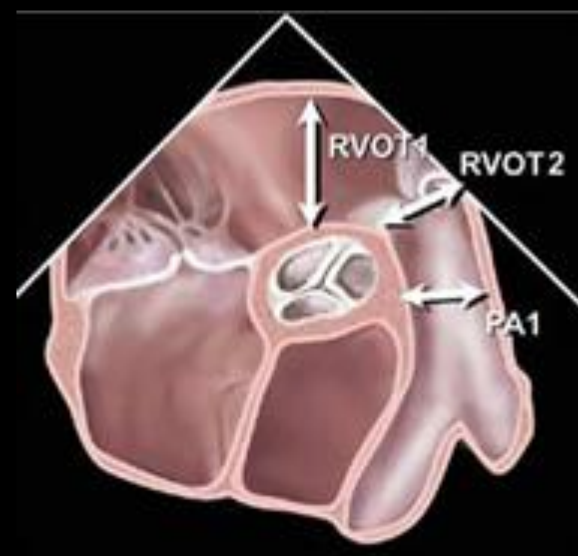
- 2 transverse Ø:
  - RV1 tricuspid annulus (hum. reference values: 33-35 mm)
  - RV2 apex of papillary muscles RV2 (hum. reference values: 23-33 mm)
- 1 longitudinal Ø:
  - RV3 center of tricuspid plane to RV apex (hum. reference values: 67-75 mm)

ASE GUIDELINES FOR RV QUANTIFICATION

RV simplified

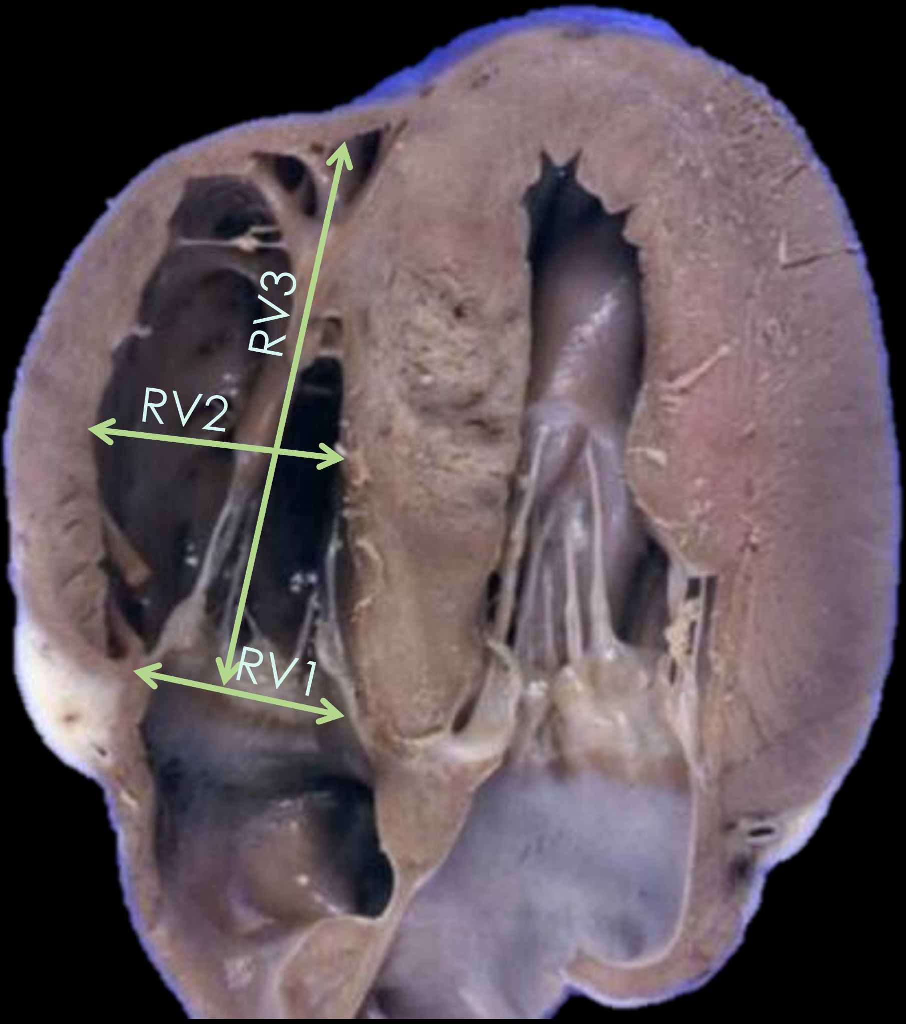


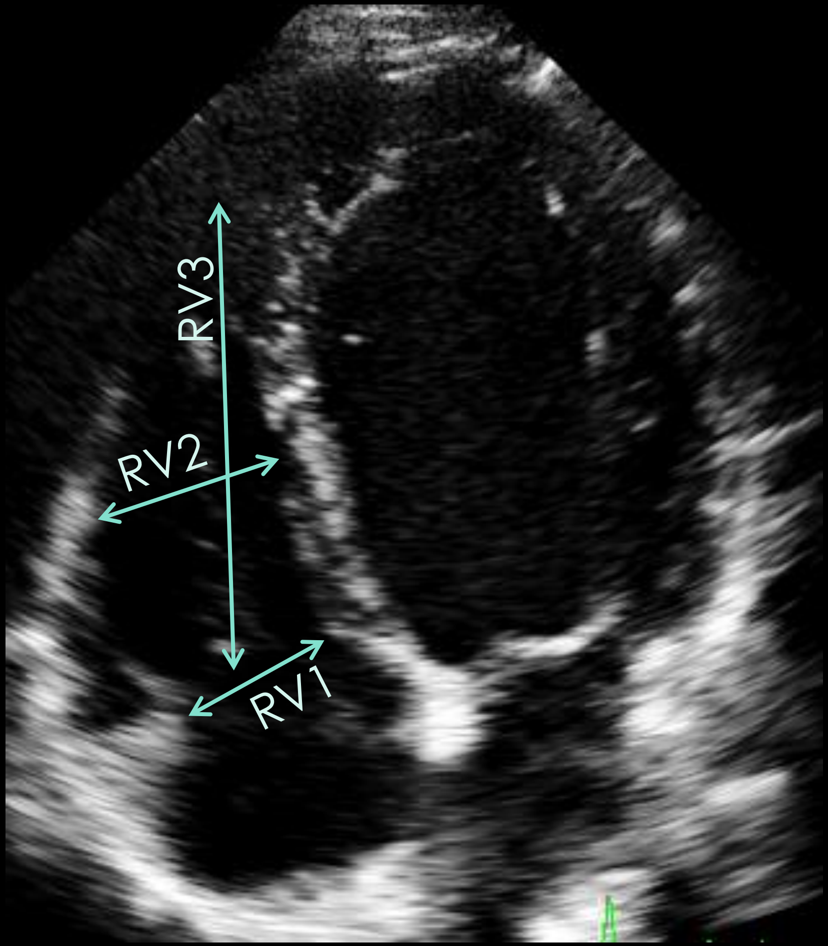
RVOT measures



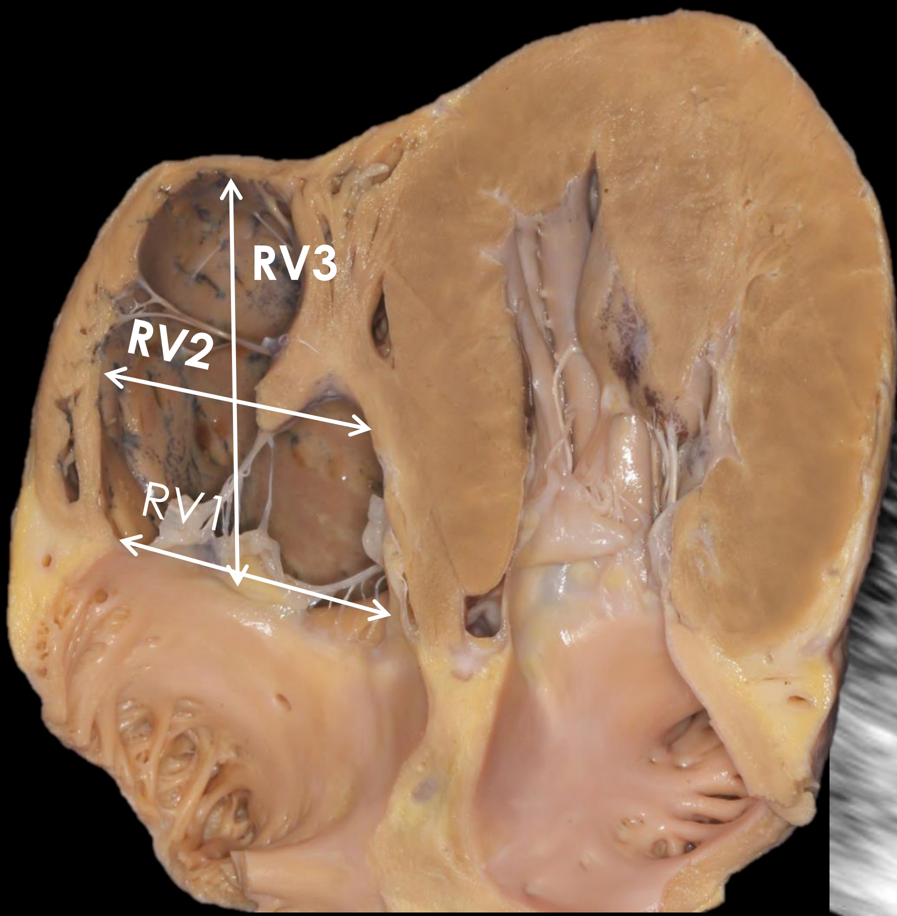
Rudski LG, et al. Guidelines for the echocardiographic assessment of the right heart in adults: A report from the american society of echocardiography. *Journal of the American Society of Echocardiography*. 2010;23:685-713

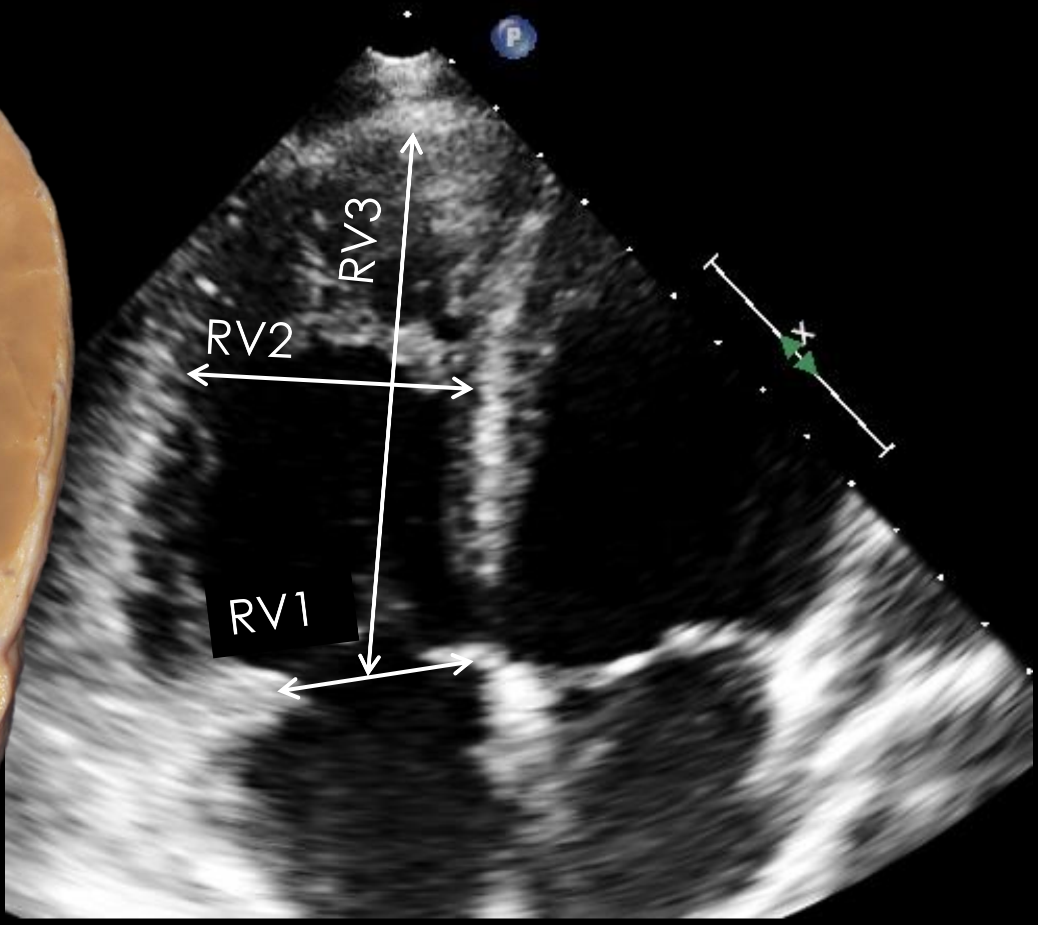
BIDIMENSIONAL RV1, RV2, RV3 MEASURES





BIDIMENSIONAL RV1, RV2, RV3 MEASURES



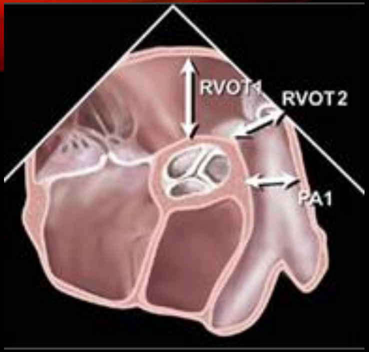


FAC OF RV INFLOW TRACT

- FAC → Fractional Area Change
- Indirect indicator of RV systolic function
- % of systo-diastolic variation of RV area measured in a dedicated 4-chamber view
- Good correlation with RV ejection fraction measured by cardiac MR
- LIMITS:
- FAC include only RV inflow tract
- Optimized view is sometime variable

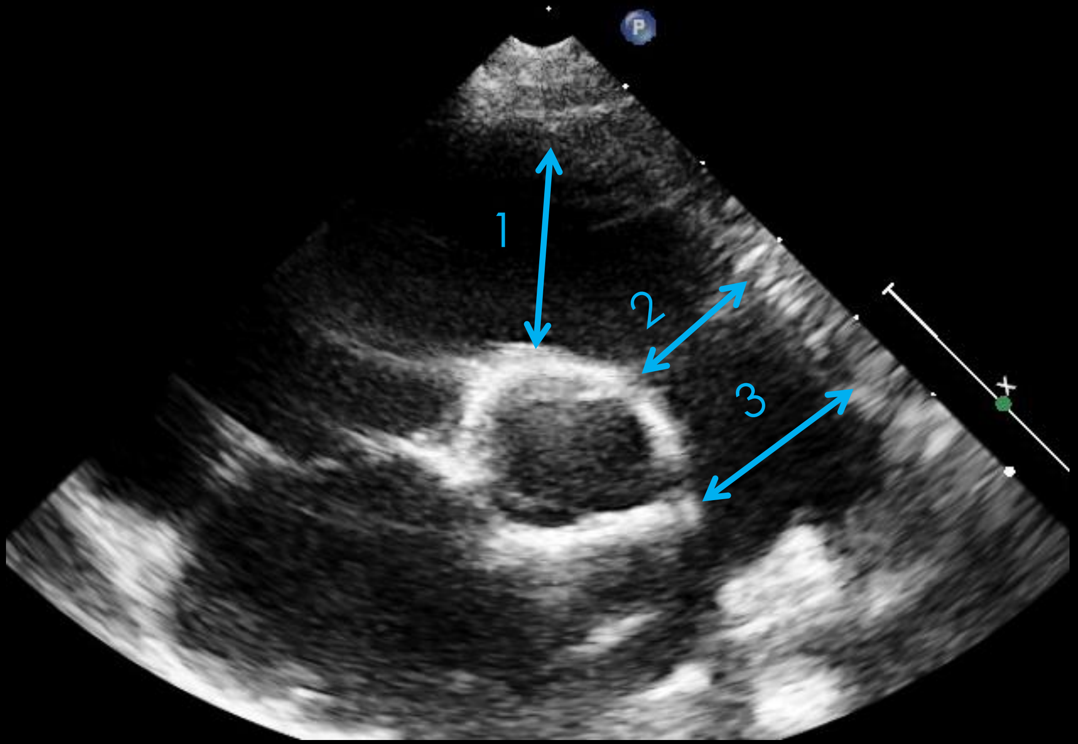
Foale R et al. Echocardiographic measurement of the normal adult right ventricle. Br Heart J. 1986;56:33-44
Zornoff LA et al. Right ventricular dysfunction and risk of heart failure and mortality after myocardial infarction. J Am Coll Cardiol. 2002;39:1450-1455

BIDIMENSIONAL RVOT, MAIN PA DIMENSIONS



Parasternal Short Axis View:

Transverse Ø of RVOT should be mapped out by a line drawn RV septum to the RVOT anterior wall at the level of right coronary cusp)

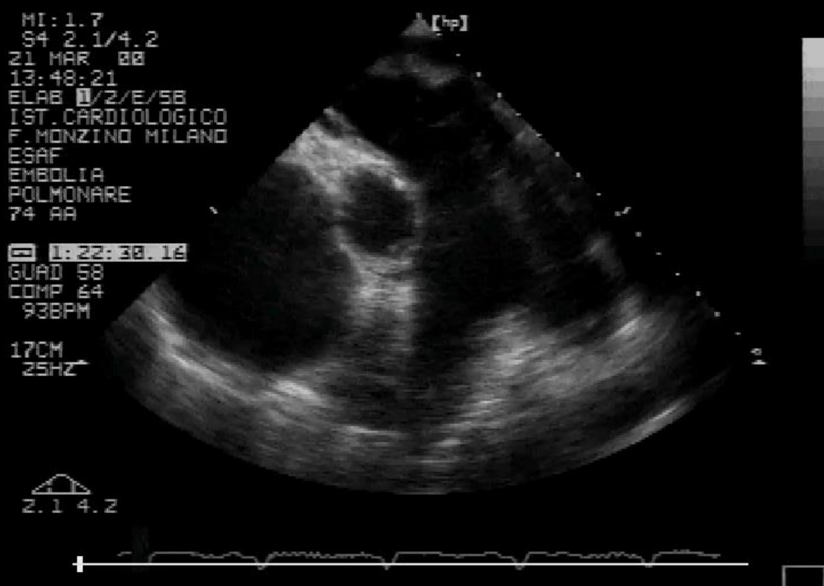


Pulmonary annulus Ø and main pulmonary artery Ø proximal to the arterial bifurcation can be measured in the same views

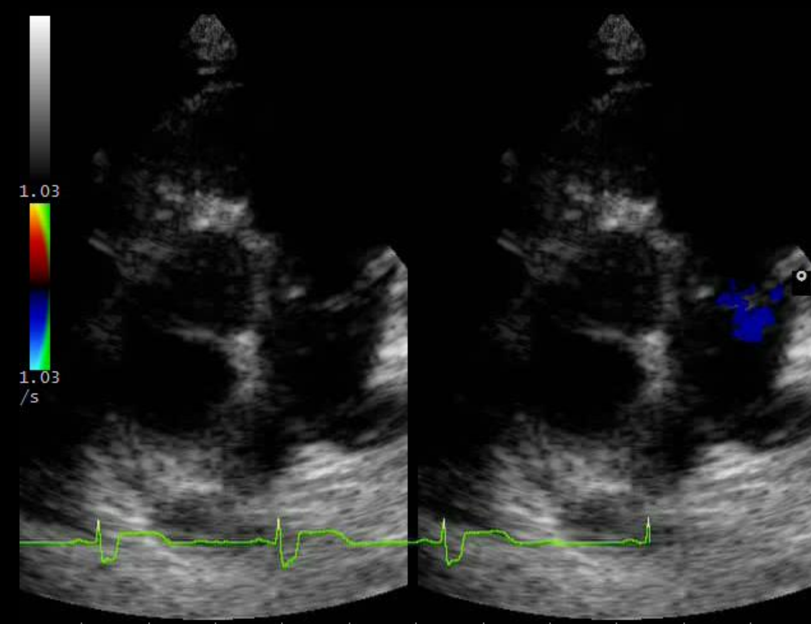
Quantitative measures of right ventricular dysfunction by echocardiography in the diagnosis of acute nonmassive pulmonary Kjaergaard J. Schaadt BK, Lund JO, Hassager C.
J Am Soc Echocardiogr 2006;19:1264-1271

BIDIMENSIONAL RVOT, MAIN PA DIMENSIONS

Pulmonary embolism



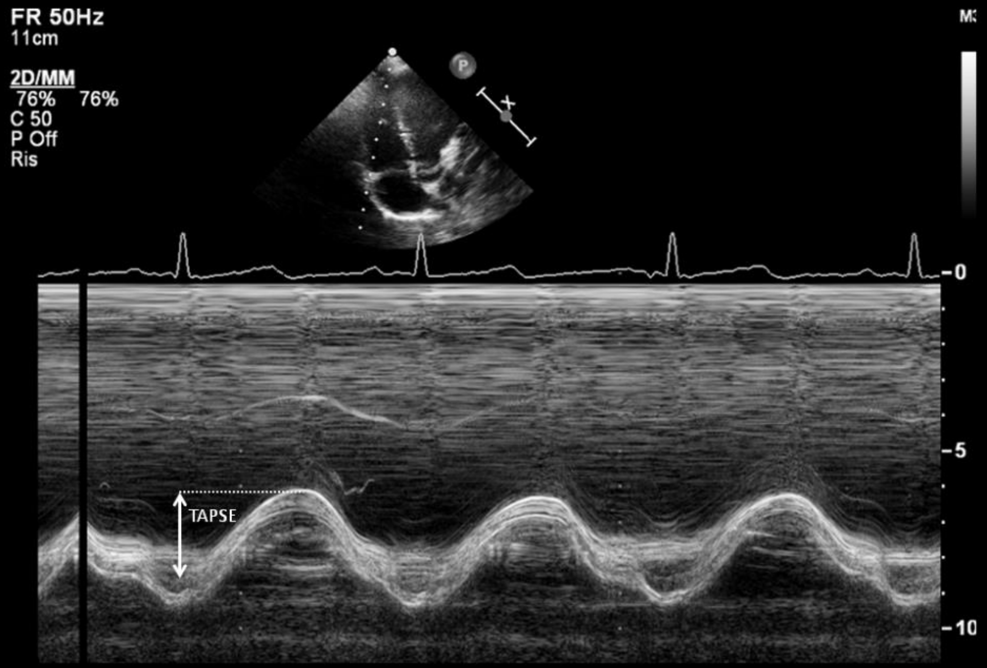
PR



TAPSE

TRICUSPID ANNULUS PEAK SYSTOLIC EXCURSION

- Widely used to study RV systolic function
- <u>BASED on the ASSUMPTION</u> that displacement of basal and adjacent segments in apical 4-chamber view is representative of the function of the entire RV
- Not valid in the regional RV wall motion abnormalities



Tricuspid annular motion

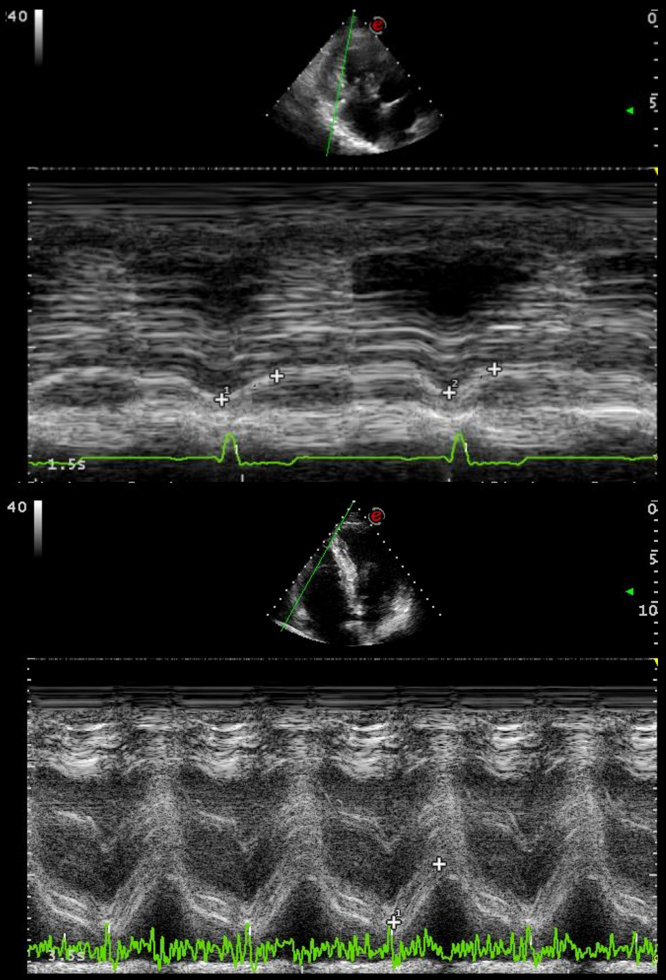
Hammarstrom E, Wranne B, Pinto FJ, Puryear J, Popp RL.

J Am Soc Echocardiogr 1991 Mar-Apr4(2):131-9

CAUTION IN THE INTERPRETATION OF TAPSE

LIMITS:

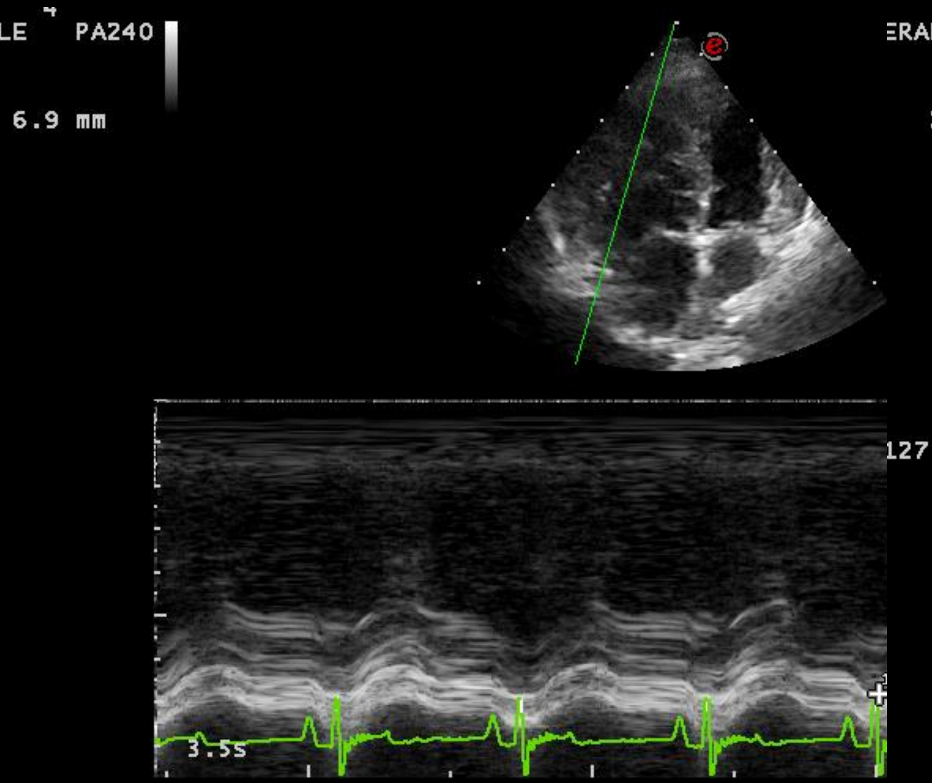
- Load Dependent
- It measure only longitudinal displacement
- Not reliable after cardiac surgery
- Reference values should take in account the RV Length



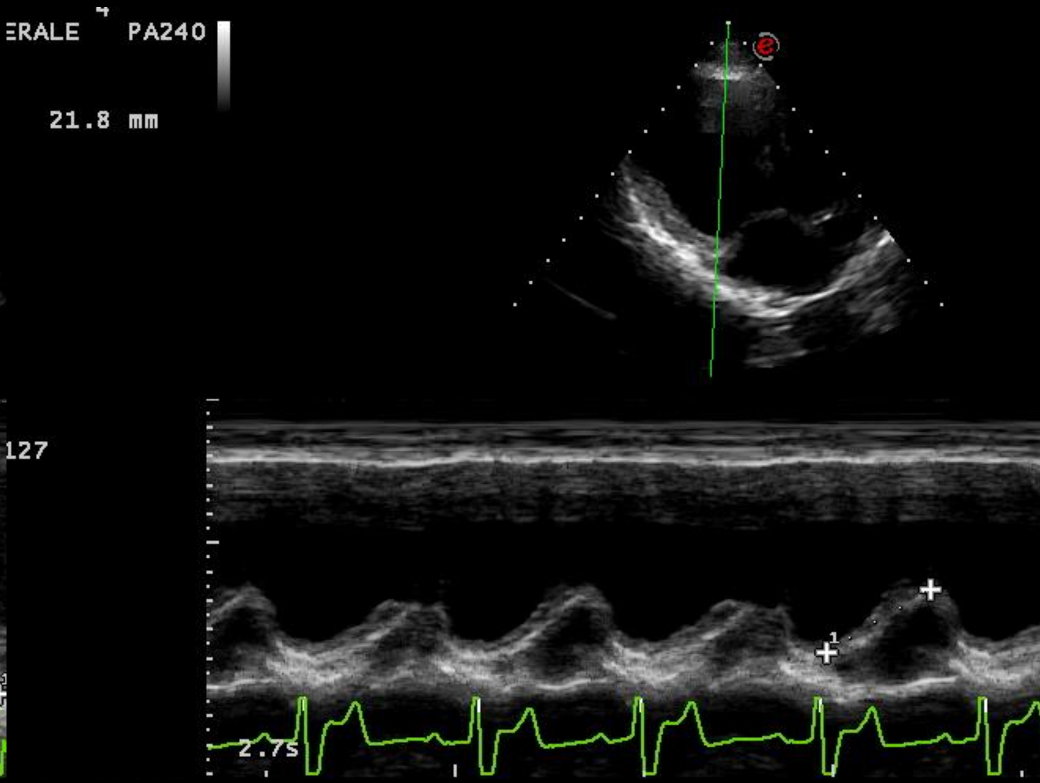
Pariaut R, et al. *J Vet Intern Med*. 2012;26:1148-1154

TAPSE

Severe PS

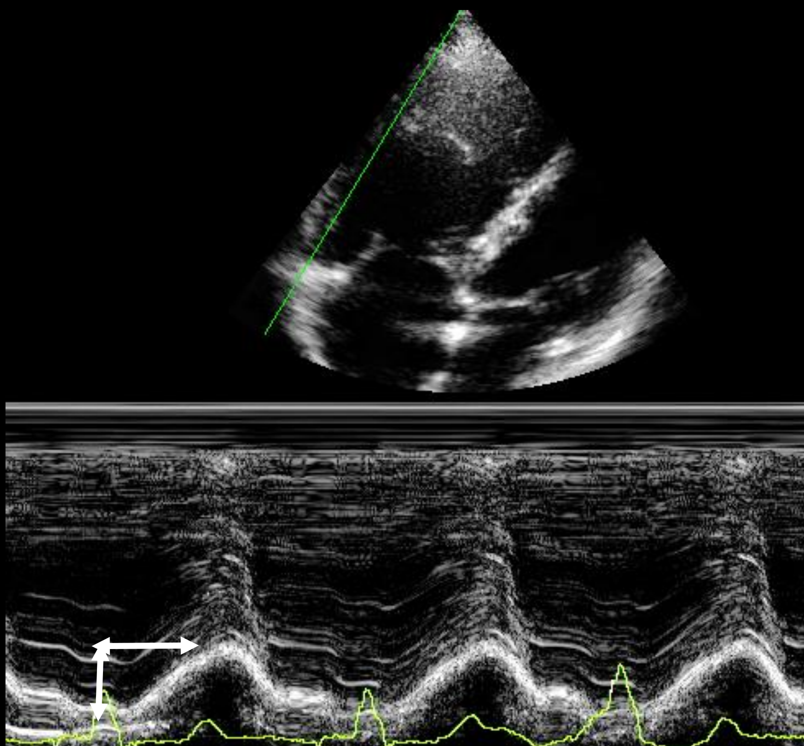


Severe PR

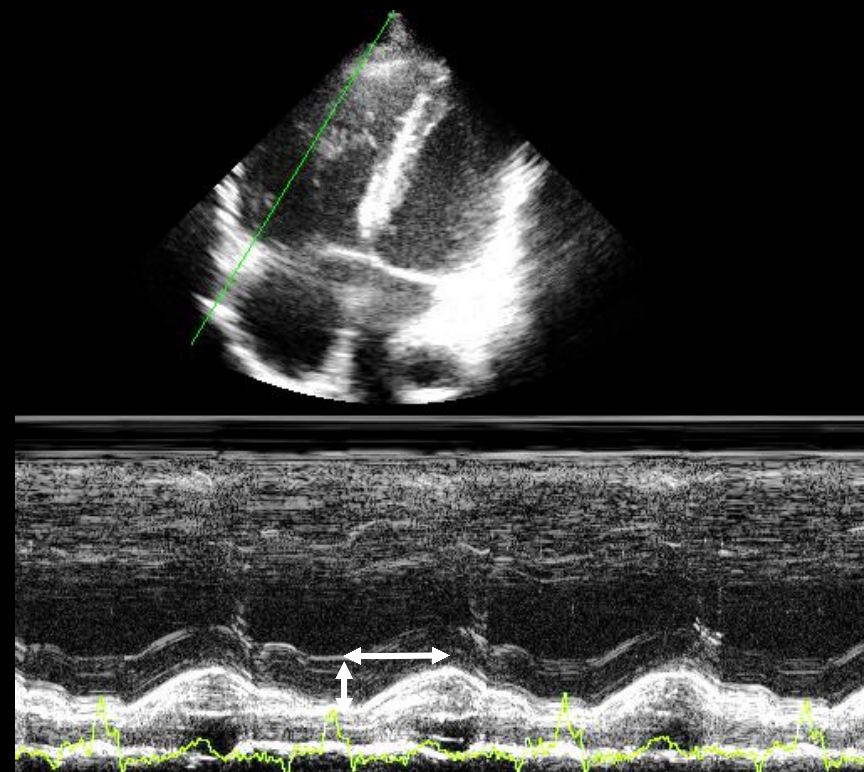


TAPSE

TAPSE 22 mm
Severe PR

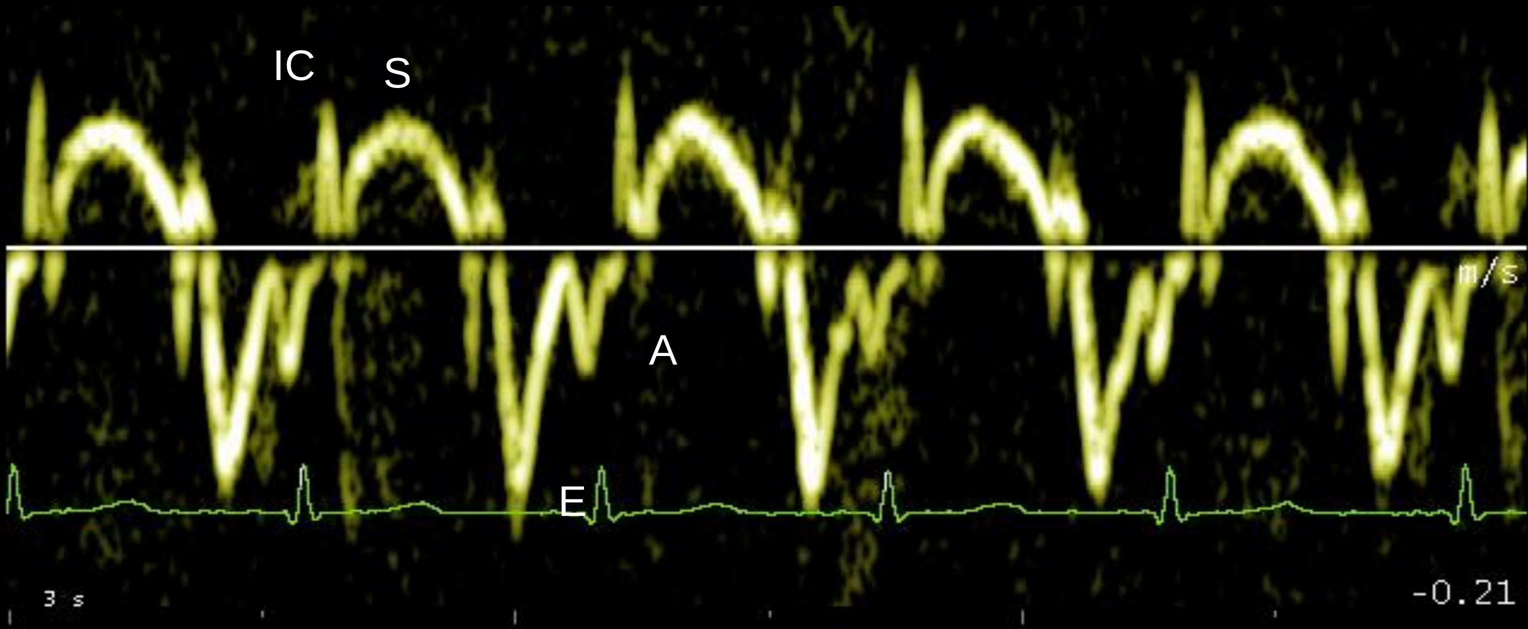


TAPSE 16 mm 24 H
after PPVI



DTI OF THE TRICUSPID ANNULUS

- IVA: Isovolumic Myocardial Acceleration
- *S*' Peak systolic velocity
- E: Early diastolic velocity
- A: Late Diastolic velocity



Characteristic of mitral and tricuspid annular velocities determined by pulsed wave Doppler tissue imaging in healthy subjects
Alam M. Wardell J, Andersson E, Samad BA, Nordlander R.
J Am Soc Echocardiogr 1999; 12 (8): 618-628

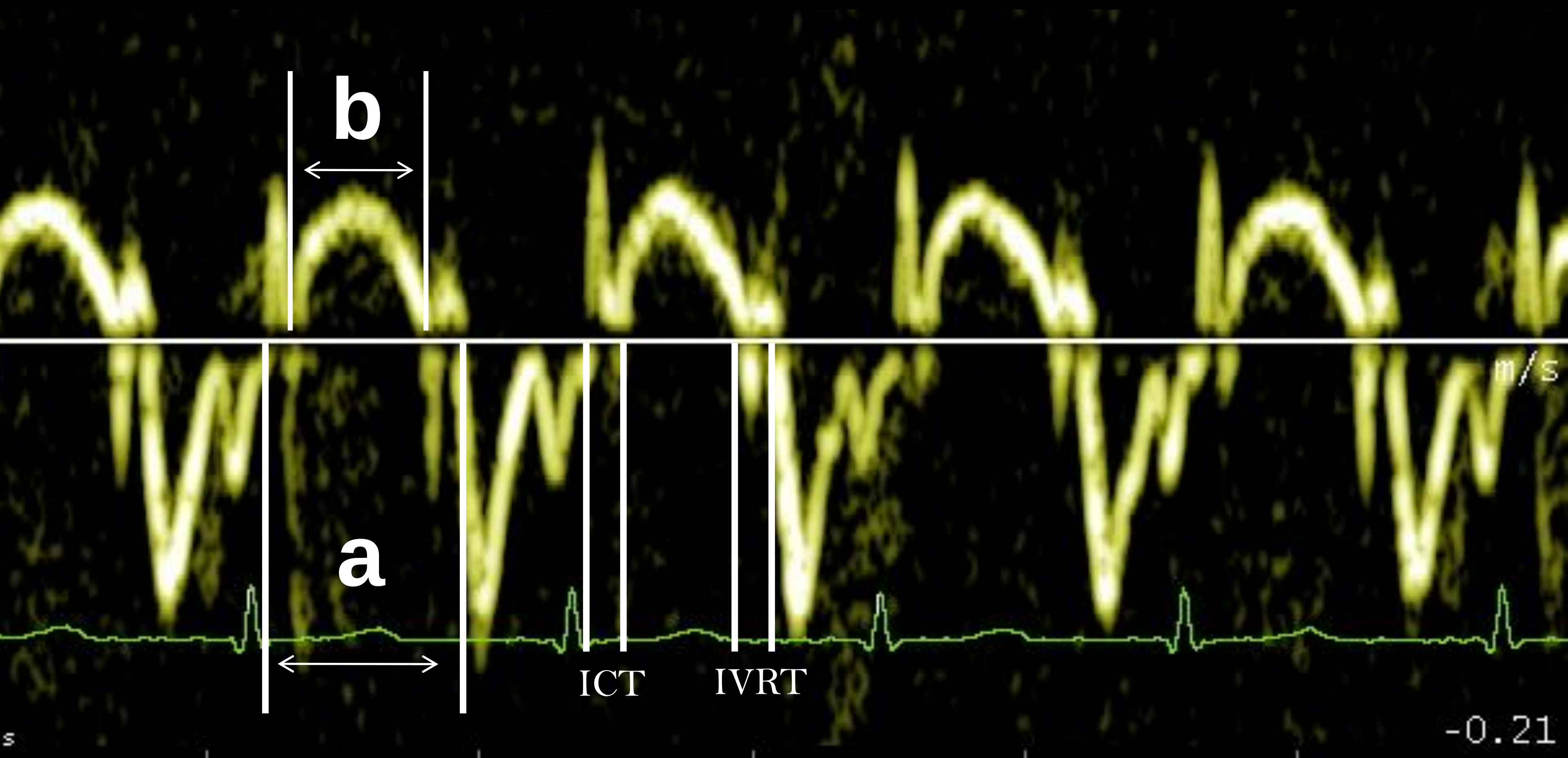
Index of Myocardial Performance (Tei)

a-b/b

IMP = (TCO-ET):ET = (ICT+IVRT):ET

Tissue Doppler method, Normal value <0.55 Pathological value >0.55

RIMP can be falsely low in conditions associated with elevated RA pressures, which will decrease the IVRT.



	Normal	PHT
ICT	38±7	85±41
IVRT	49±9	135±43
ET	322±21	241±43
Tei	0.28±0.04	0.93±0.34

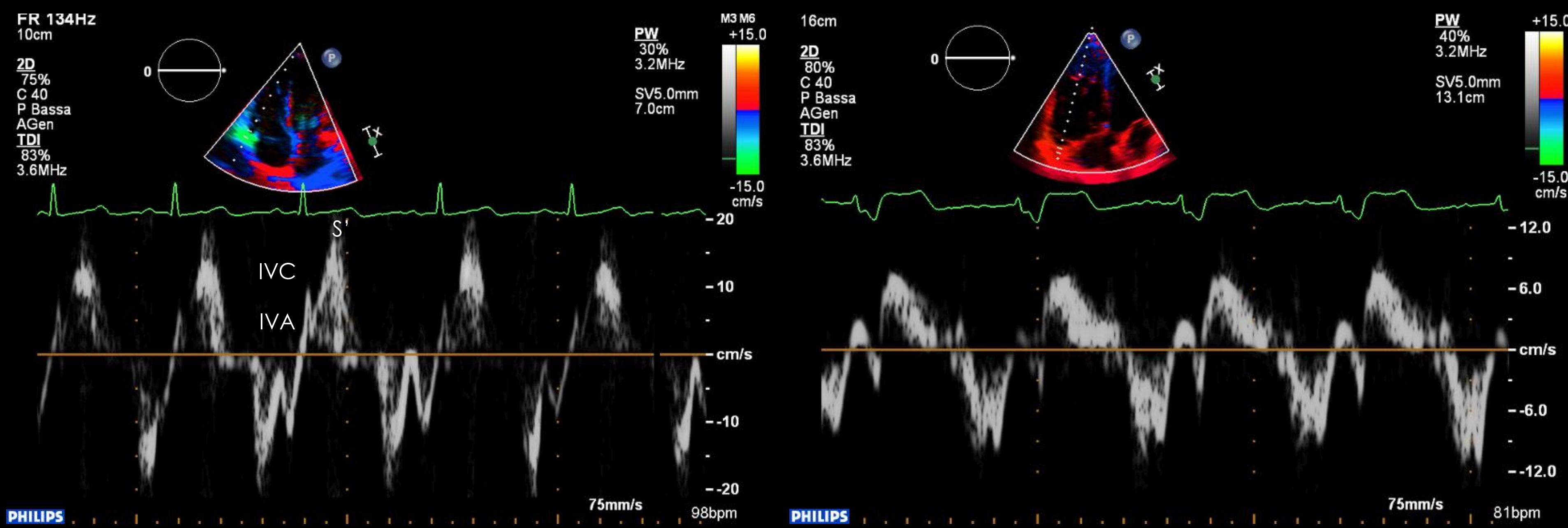
ISOVOLUMIC ACCELERATION (IVA)

Acceleration of the myocardium during isovolumic contraction (IVA)

- Index of contractile function, comparing it to myocardial acceleration, and velocities measured during the ejection phase.
- Several clinical ands experimental validation.

Vogel M, et al. Circulation. 2002;105:1693–1699
Frigiola A, et al. Circulation. 2004; Suppl 110:I53–57.

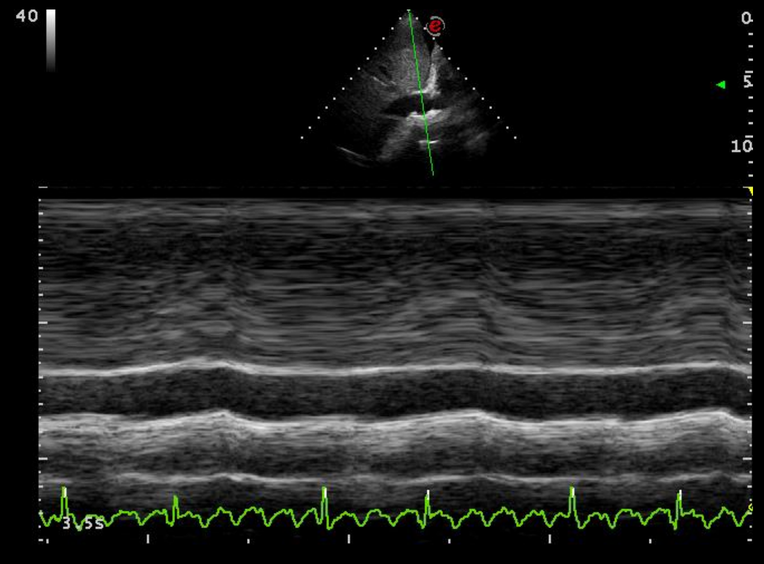
ISOVOLUMIC ACCELERATION (IVA)

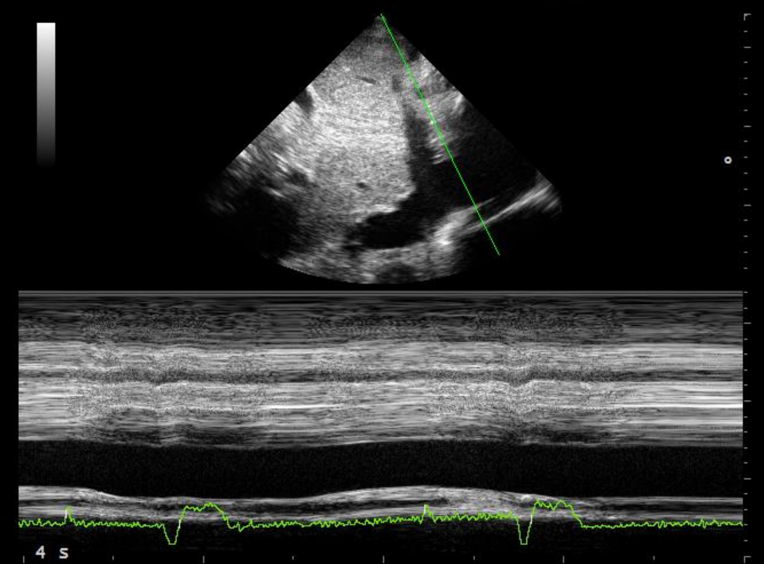


VENA CAVA CONGESTION

- Normal IVC collapsibility
  - RAP 6 mmHg
- IVC collapsibility 35-45%
  - RAP 9 mmHg
- IVC collapsibility < 35%
  - RAP 16 mmHg

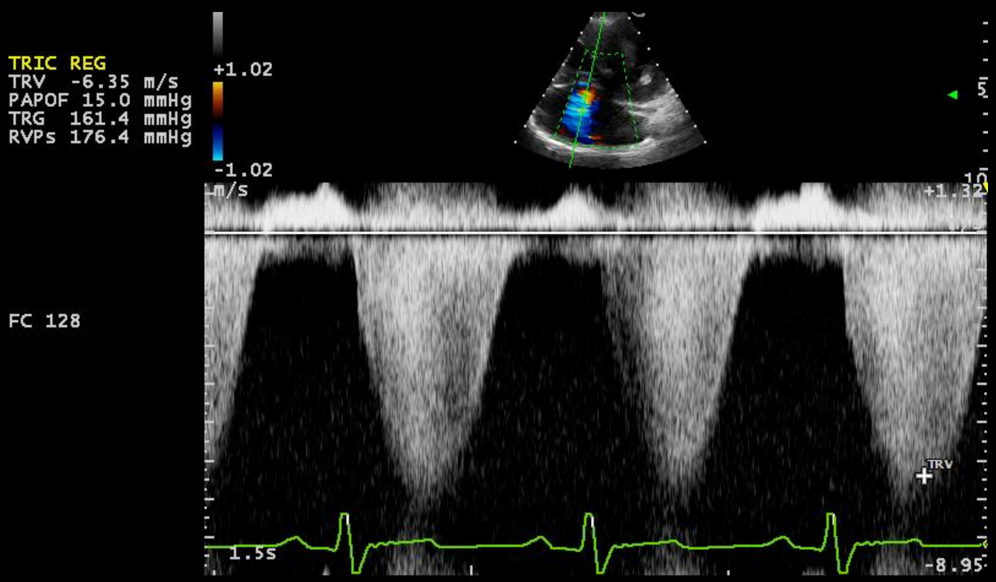
Pepi M. et al J Am Soc. Echoc. 1994



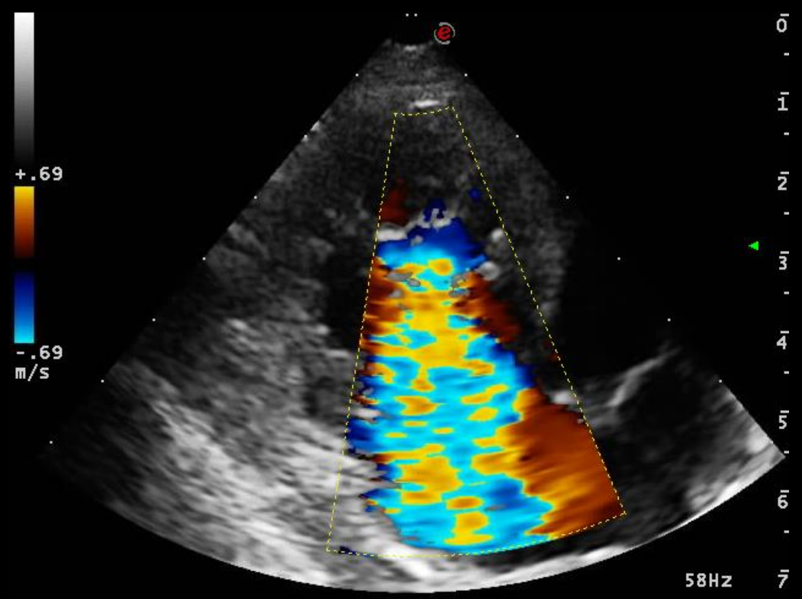


TRICUSPID REGURGITATION

Velocity

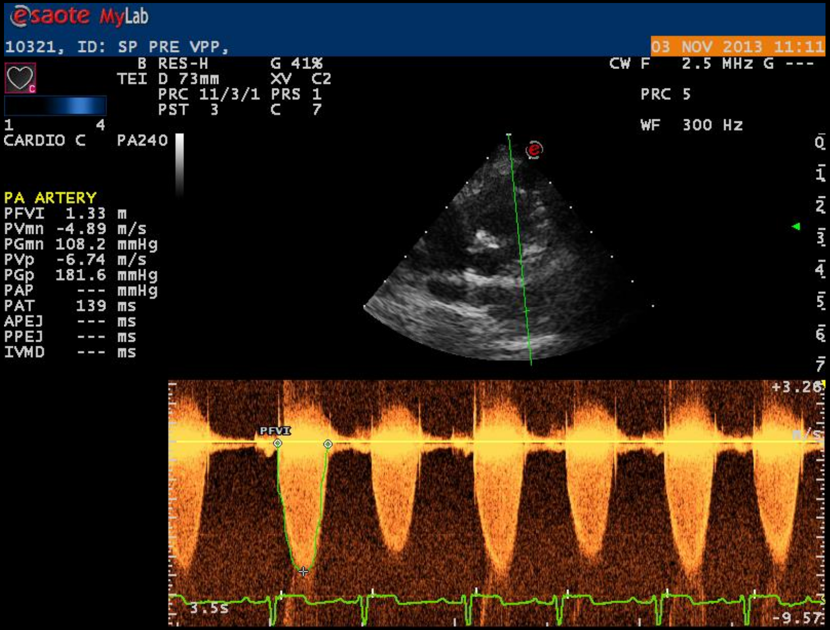


Quantity

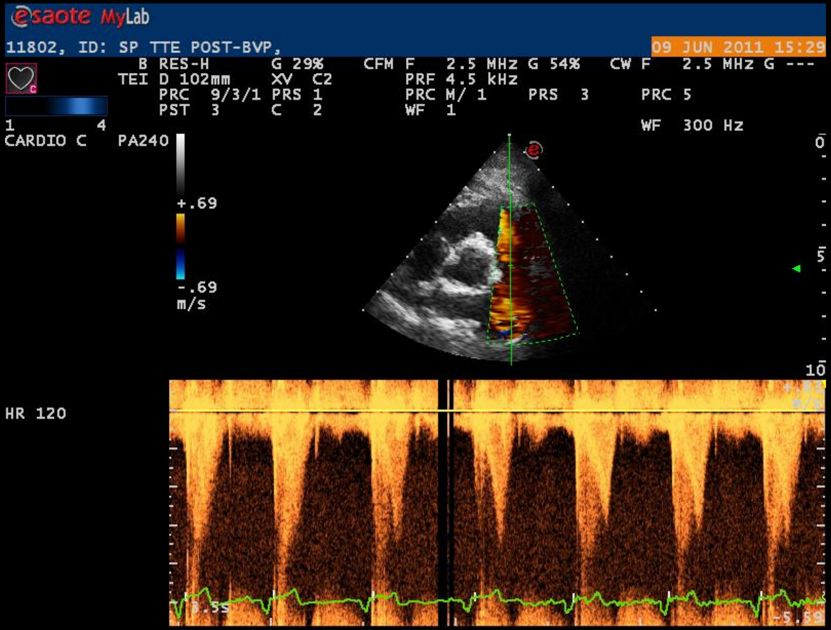


ANTEROGRADE PULMONARY FLOW

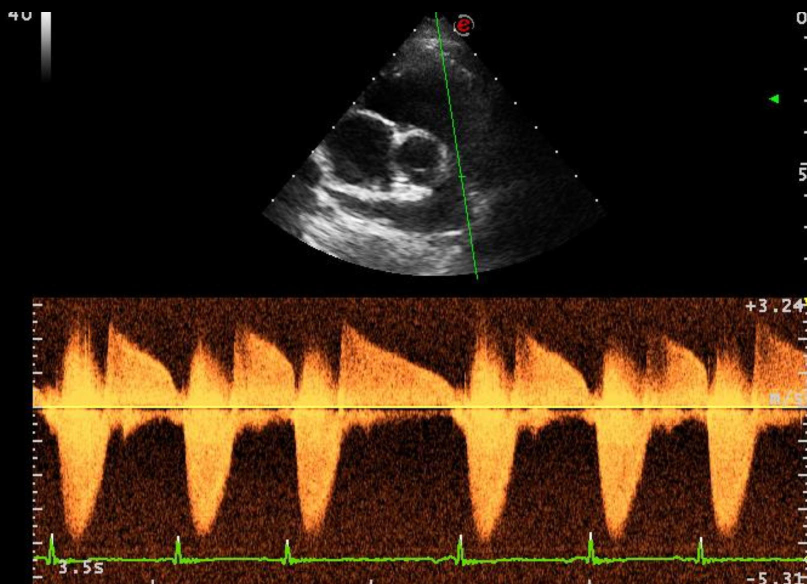
Severe Stenosis

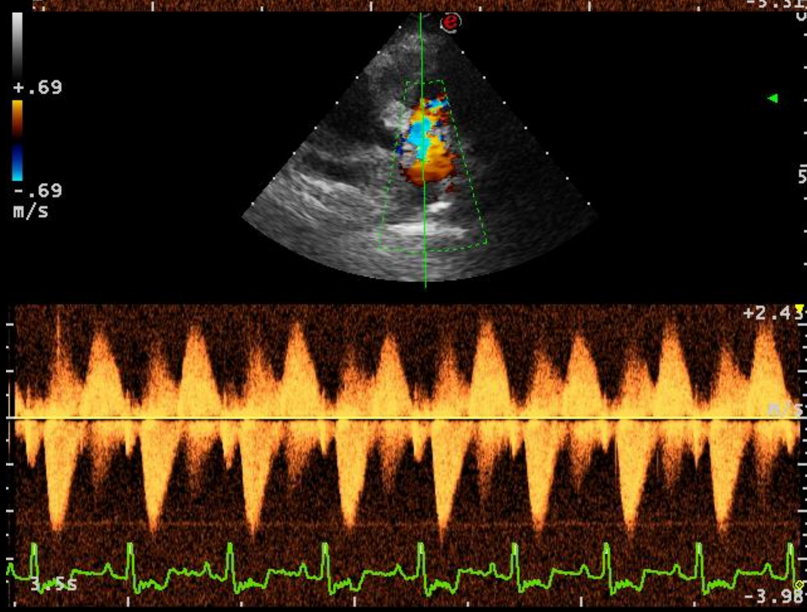


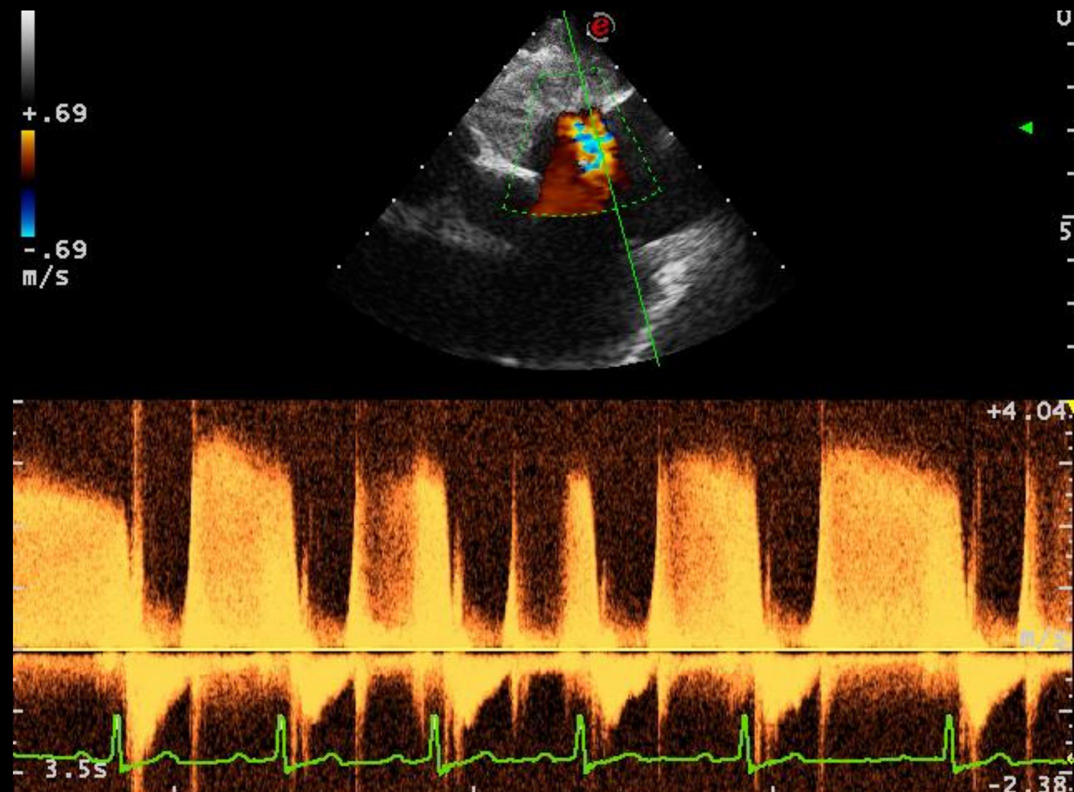
Dynamic Stenosis



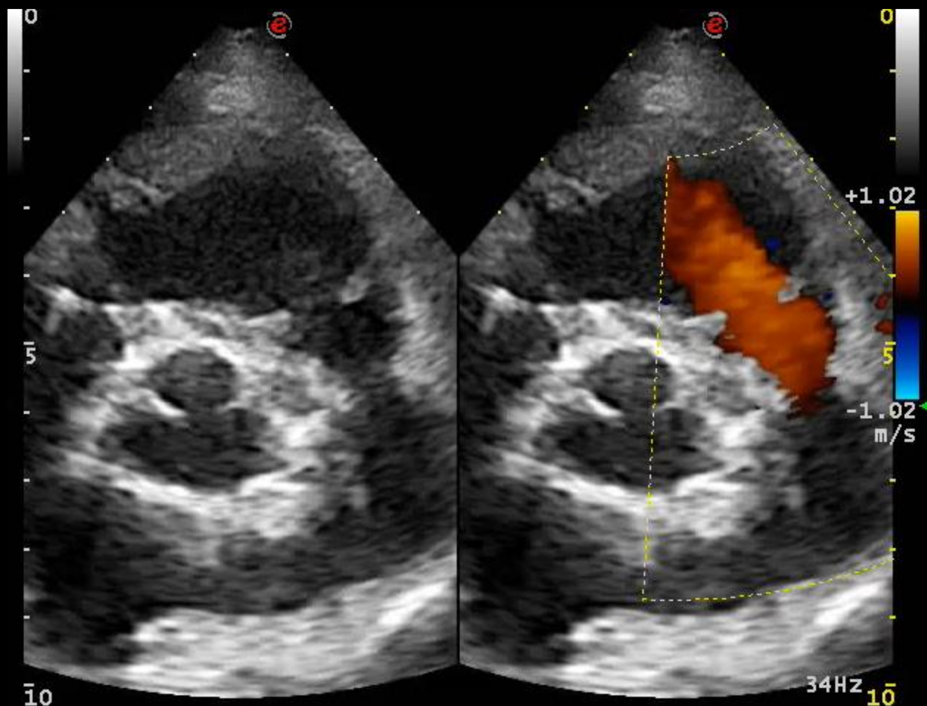
PULMONARY REGURGITATION

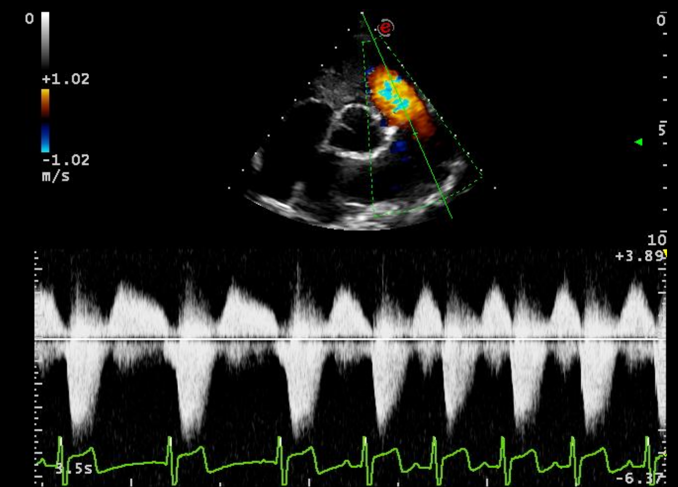


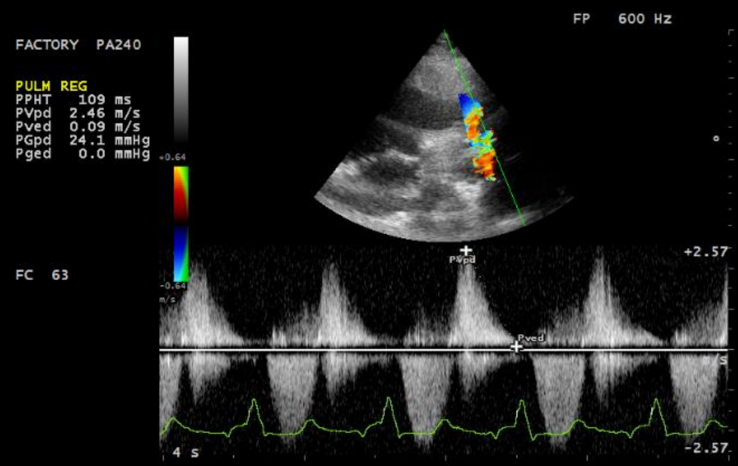




PULMONARY REGURGITATION







ELSEVIER

International Journal of Cardiology 115 (2007) 86 – 89

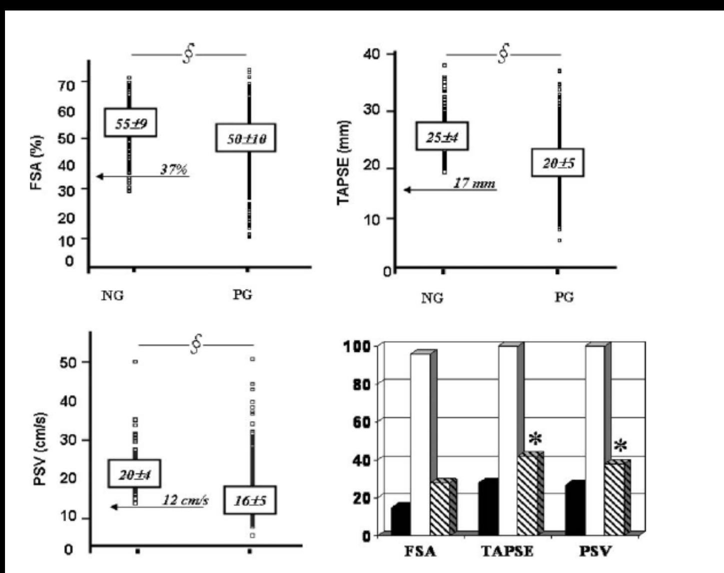
International Journal of Cardiology

www.elsevier.com/locate/ijcard

Letter to the Editor

Feasibility and accuracy of a routine echocardiographic assessment of right ventricular function

Gloria Tamborini *, Mauro Pepi, Claudia Agnese Galli, Anna Maltagliati, Fabrizio Celeste, Manuela Muratori, Salehi Rezvanieh [1], Fabrizio Veglia



Aims of the study were to evaluate the feasibility of a routine use of FSA, TAPSE and PSV as measures of RV systolic function in 900 patients, including 750 pathological (PG) and 150 normal subjects (NG) matched for age, referred for transthoracic echocardiography in our laborato-

FSA, TAPSE and PSV were recorded in all cases in a mean time of 3±1 min. Inter- and intra-observer variabilities were very low for TAPSE (0.24±1.3 and 0.17±1.4 mm, respectively) and PSV (0.15±1.8 and 0.21±1.5 cm/s) and high for FSA (4.22±7% and 1.1±3.9%.), due to a limited definition of the endocardial border in

RV dimensional and functional parameters

- RV Fractional area; TAPSE
- DTI (annular velocities)
- Pulmonary systolic pressure and RA Pressure

Routine evaluation in 1000 cases

6 + 1 minutes

Tamborini et al Int J Cardiol 2006