Great Ormond Street Hospital for Children NHS Foundation Trust

UCL

Right Ventricular Function

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No disclosures

Right ventricular function: questions to be answered

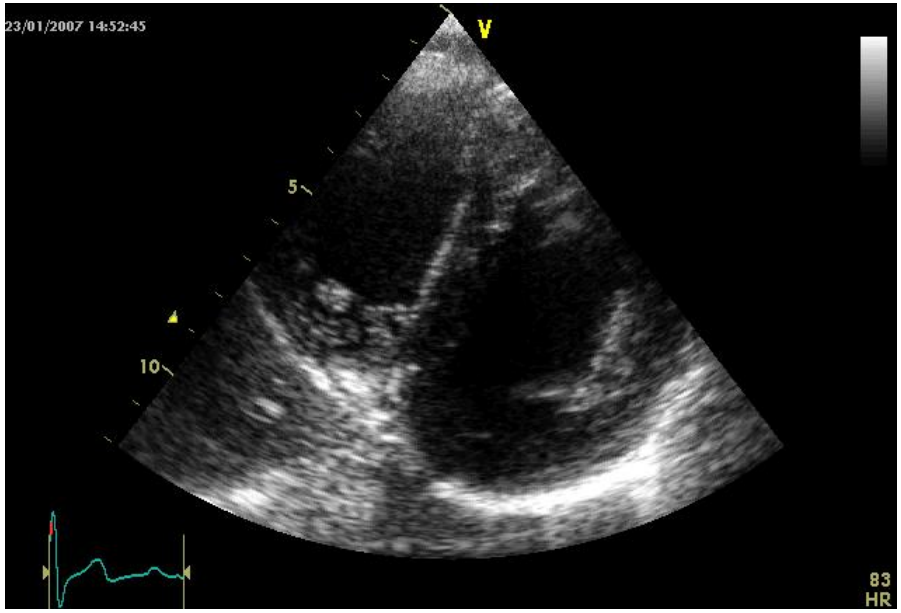
- Why fetal RV myocardium exposed to high afterload does not tolerate high afterload postnatally? **(PH)**

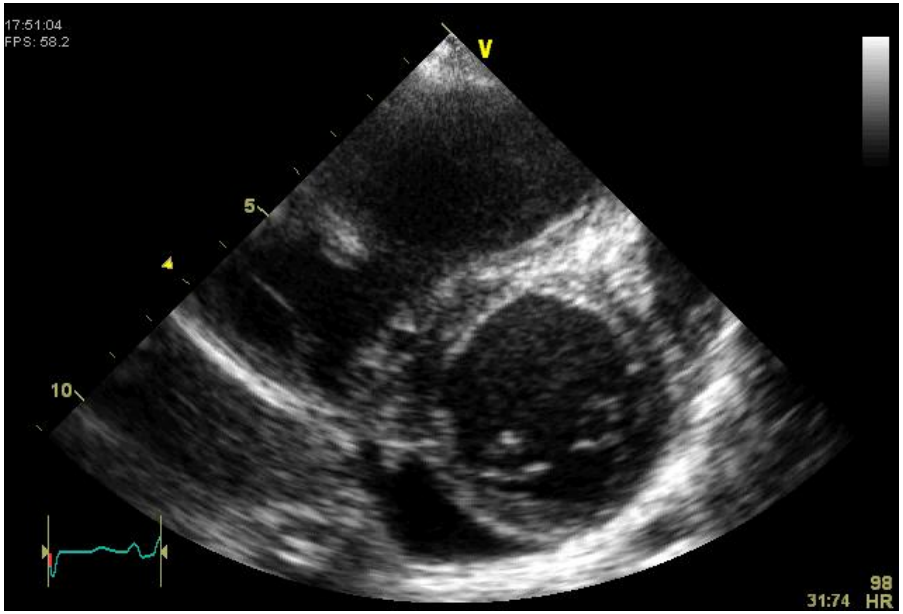
- Why conversely RV myocardium tolerates high afterload for decades? **(ccTGA)**

- Why RV myocardium tolerates high preload postnatally even for years **(PR in TOF, ASD)** but prenatally tends to fail within the days **(SVT, TTTS)**

- Why **Eisenmenger patients** are doing clinically better than **Pulmonary Hypertension patients**?

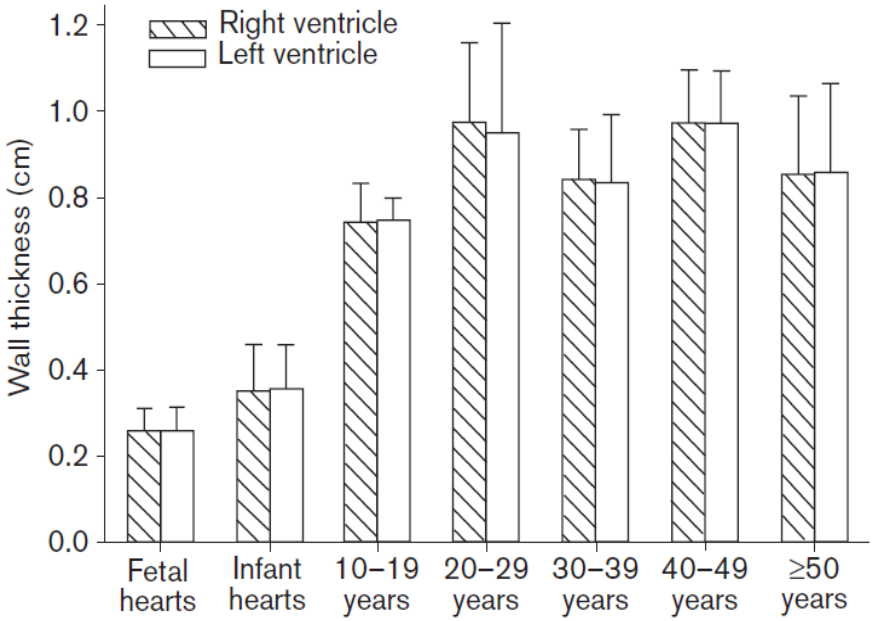
Systemic RV Eisenmenger sy	Pulmonay arterial hypertension

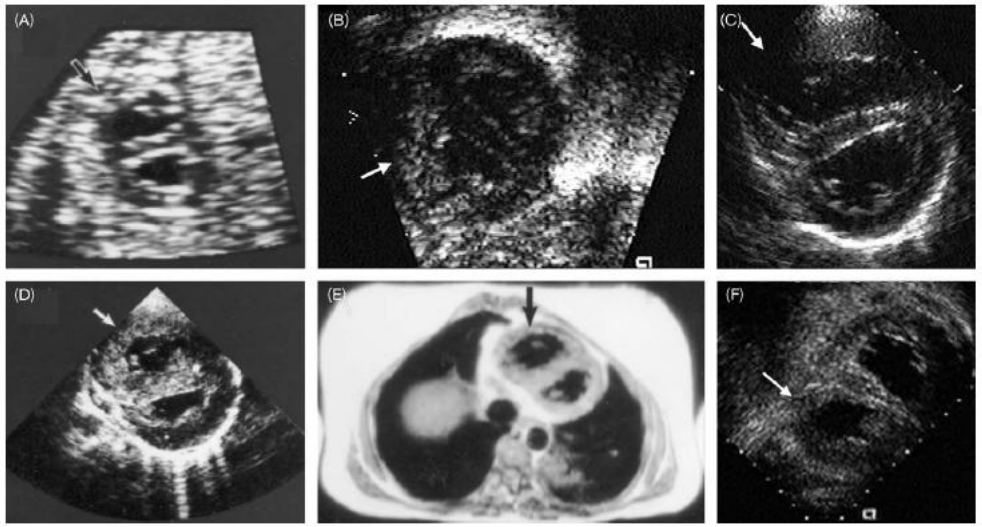




Same age patients

Eisenmenger syndrome





In patients with Eisenmenger syndrome, **regression of right ventricular wall thickness never occurs** and **contractile function is preserved** for life in the majority of patients

Hopkins WE, Coron Art Dis 2005

Postnatal RV adaptation

- **Differences between fetal and postnatal myocardium** in energy metabolism, *myosin heavy chain* and *collagen* characteristics and *intra- extracellular components*

- With the **fall of PVR postnatally**, RV remodels to a low pressure, high compliance chamber and becomes **sensitive to high afterload**

- **Chronic pressure loaded RV** (Eisenmenger s) adapts a transition to a so-called ***"fetal gene program"*** with a shift from *alpha to beta myosin heavy chain expression*, an *increase in adrenergic receptors*, *calcineurin activation* and *increased phosphodiesterase type 5 expression*

Right Ventricle: Morphological and Functional Considerations

RV function

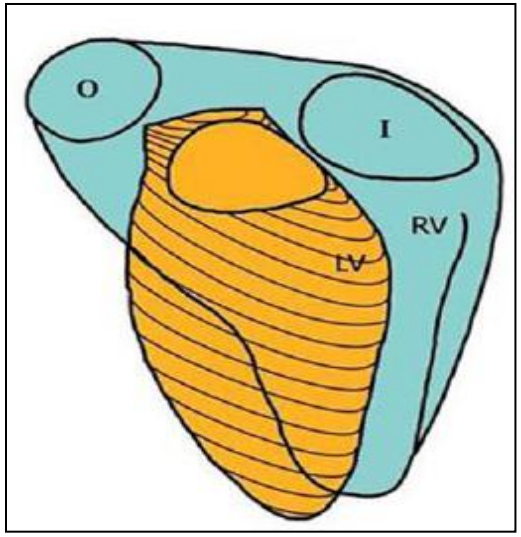
Peristaltic wave contraction from the inflow to the outflow regions, propelling the blood in the direction of the outflow tract

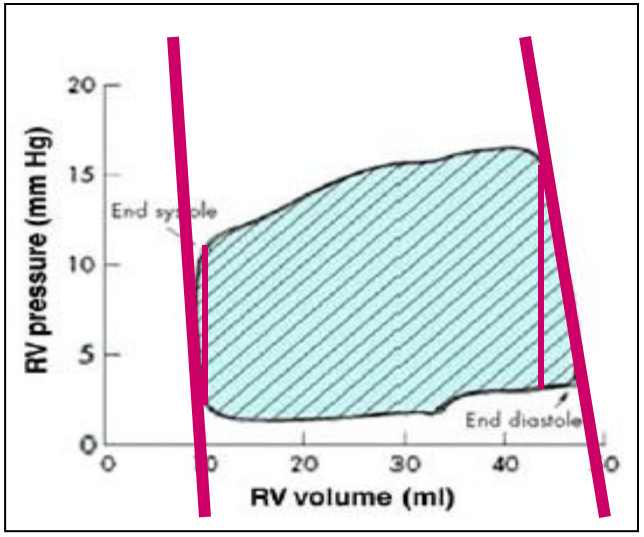
Mechanism of RV contraction:

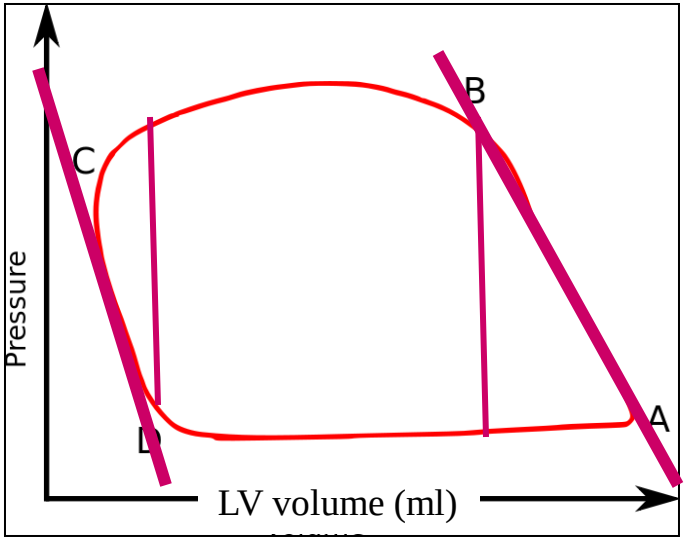
- **Inward movement** of the free wall (bellows effect)
- **Contraction of longitudinal fibers (deep layer)** (long axis shortening)
- **Contraction of circumferential fibers (superficial layer) and traction on the free wall** at points of attachment secondary to LV contraction

Asynchronous (peristaltic) contraction pattern

Interdependence with LV – Septal function !







- RV stroke volume same as in LV but **RV stroke work less by 25%** (less energy cost)
- Trapeziodal shape of RV:

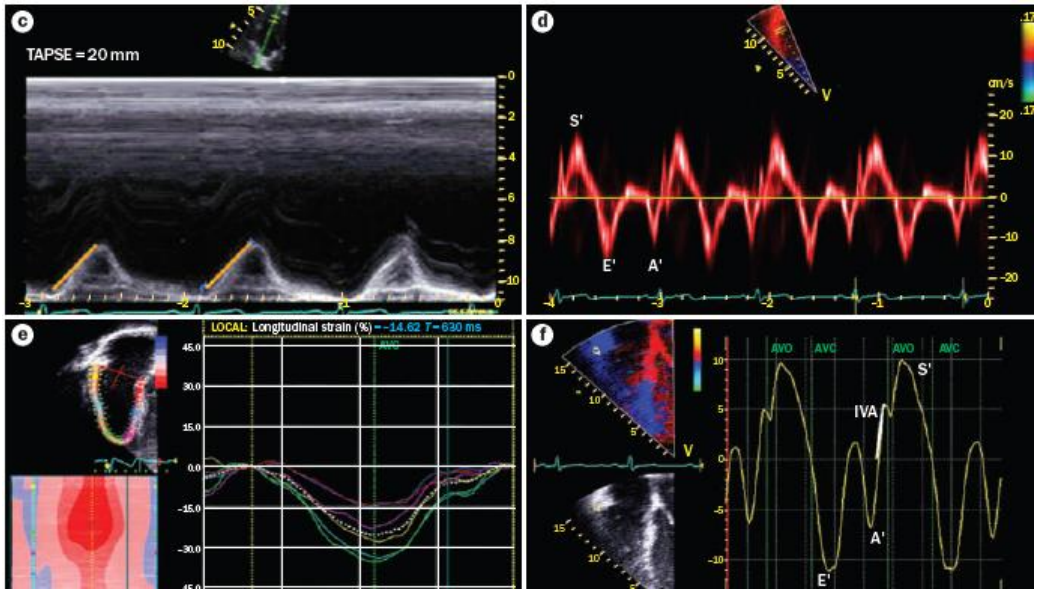
  During systole, RV systolic pressure exceeds rapidly low PA diastolic pressure resulting in very **short RV isovolumic contraction**

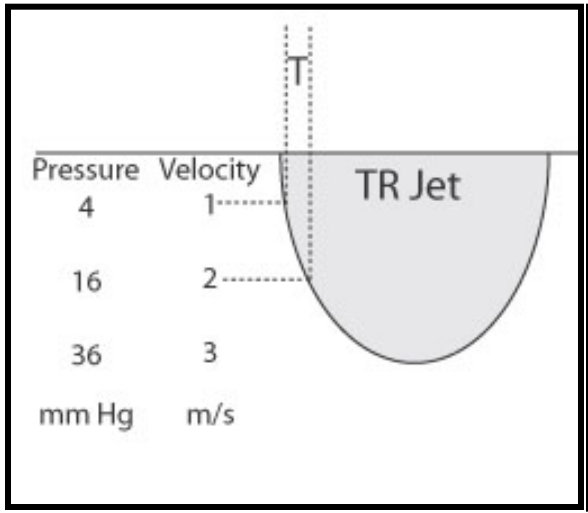
  Similarly during diastole, rapid pressure equilibrium between PA and RV results in **even shorter isovolumic relaxation**

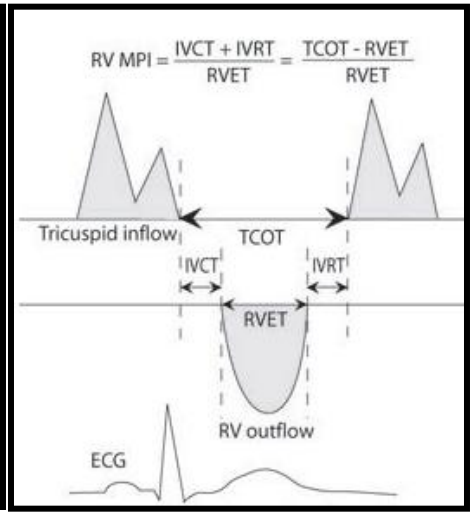
Vitarelli A, Heart Fail Rev 2010

RV function: Echocardiographic Challenges

- Eye balling
- FAC (%)
- TAPSE (mm)
- M-mode (AMM)
- S/D ratio
- +dP/dt (systemic RV)
- MPI (Tei) index
- TDI (Strain, -SR)
- RT-3DE







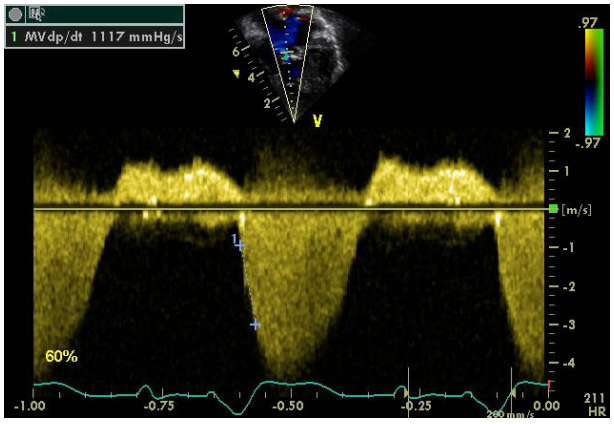
J Am Soc Echocardiogr 2010

EHJ-Cardiovascular Imaging 2015

+dP/dt: role of loading conditions

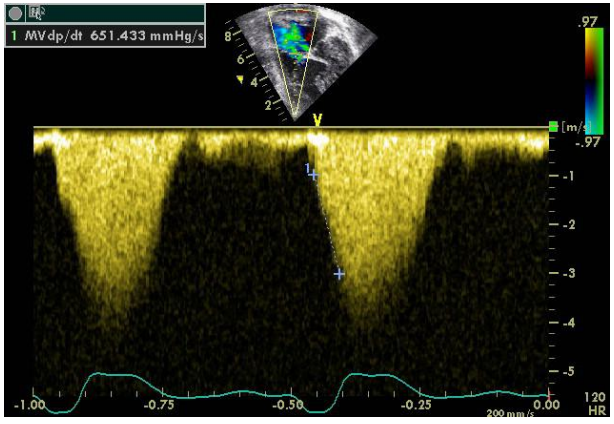
Fontan pt. on V-A ECMO
(bridge to recovery)

Full flow ECMO



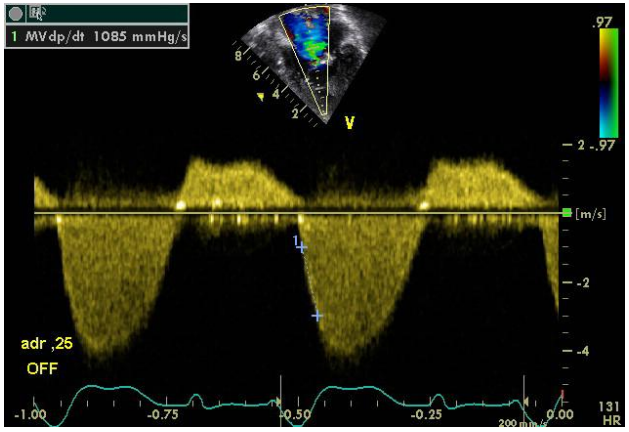
1,117 mmHg.s-1

30% flow ECMO



611 mmHg.s-1

Off ECMO
+
Adr 0.01, Mil 0.5

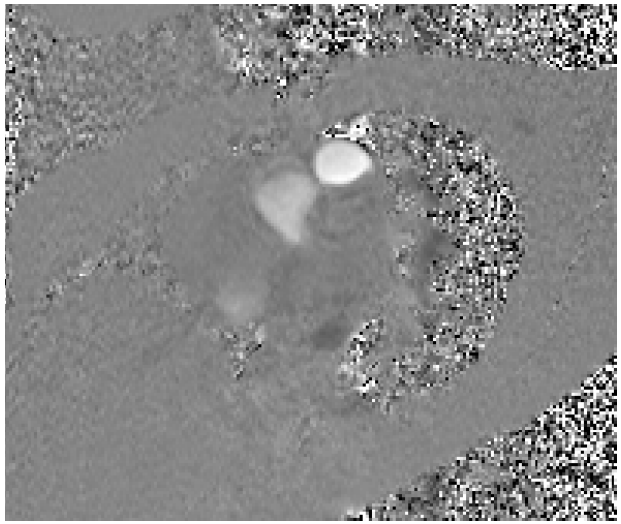


1,085 mmHg.s-1

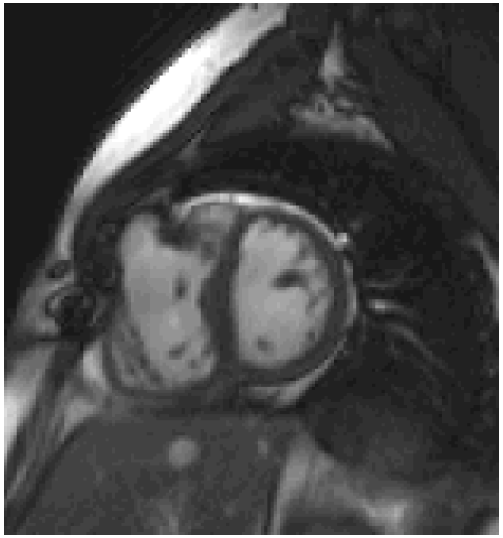
Magnetic Resonance Imaging

- RV and LV function

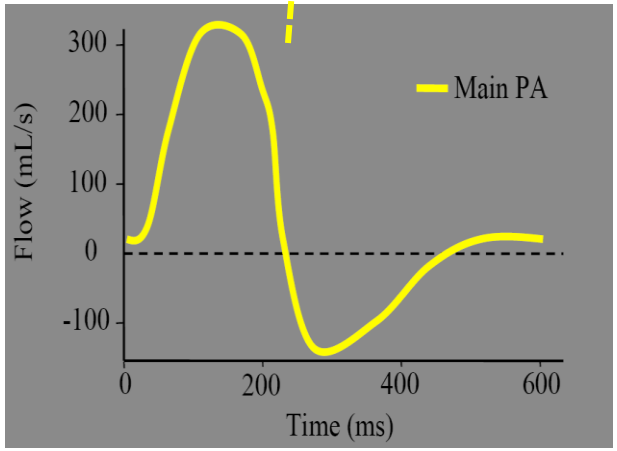
  (RVEDV, LVEDV, RVEF, LVEF)
- Flow: RF, shunts (Qp:Qs)
- PVR (±)



pre



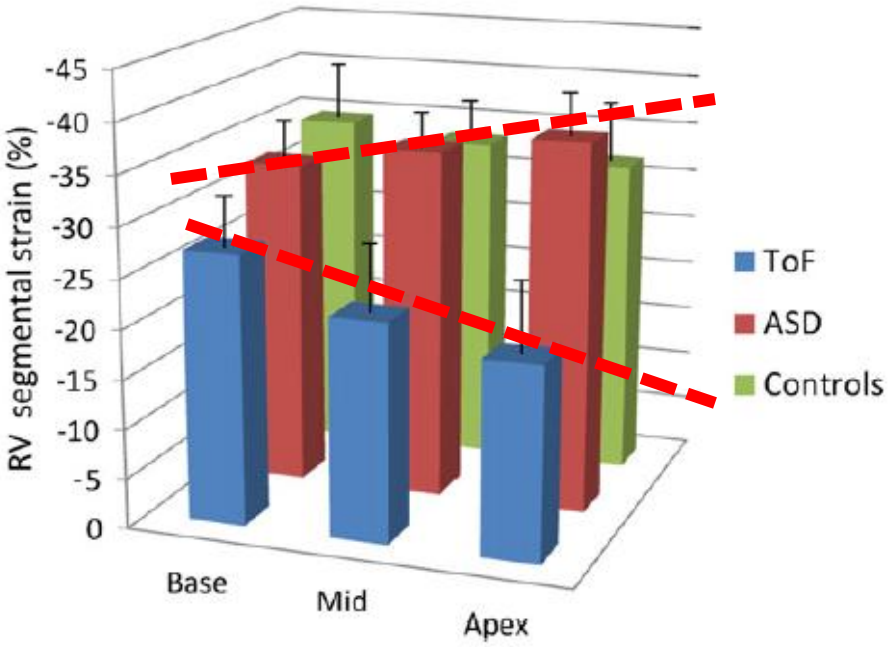
post

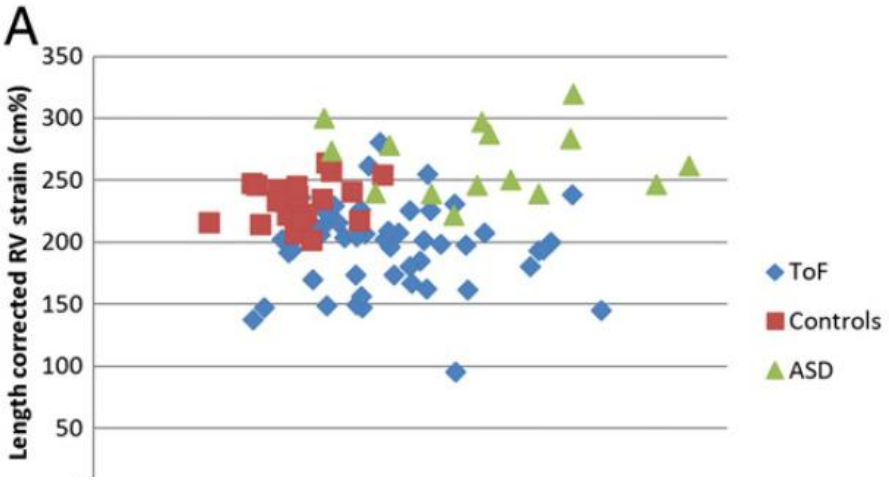


Right Ventricle

Exposed to High Preload

RV function in ASD vs TOF+PR



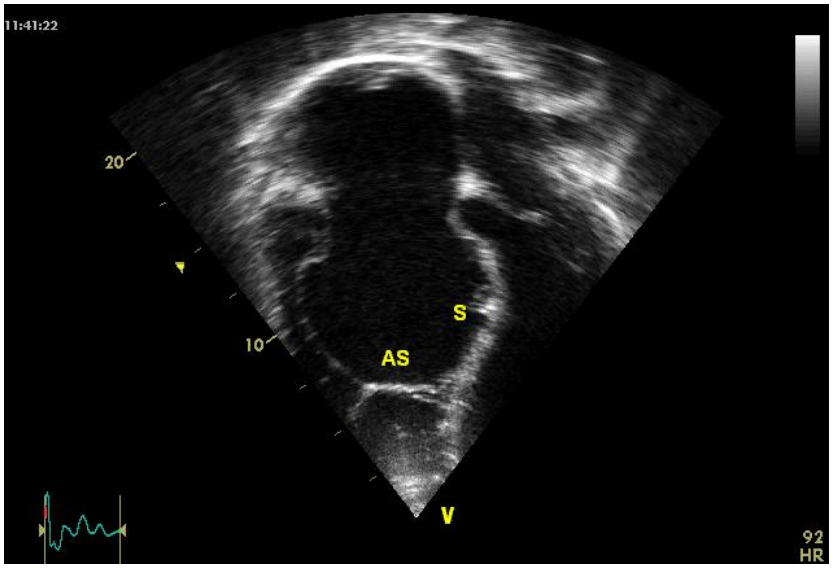


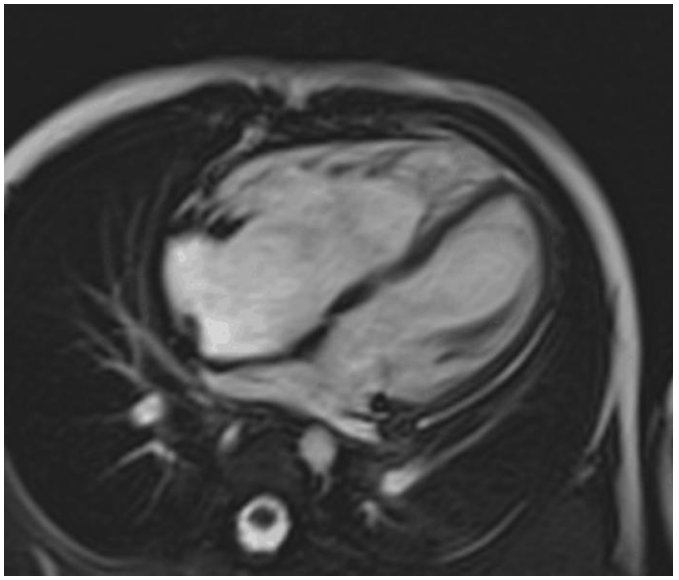
RV myocardial strain corrected by RV length

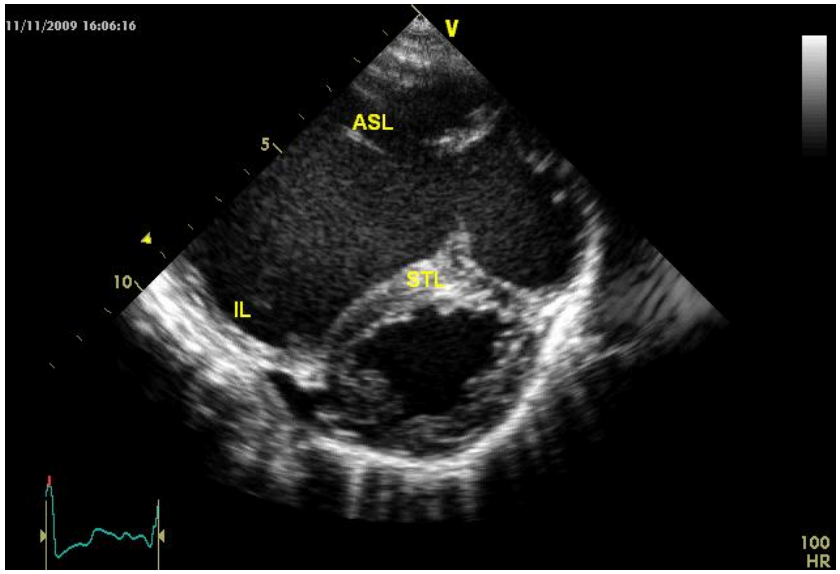
- Different adaptation mechanism in both diseases with mainly **apical segments affected in TOF**

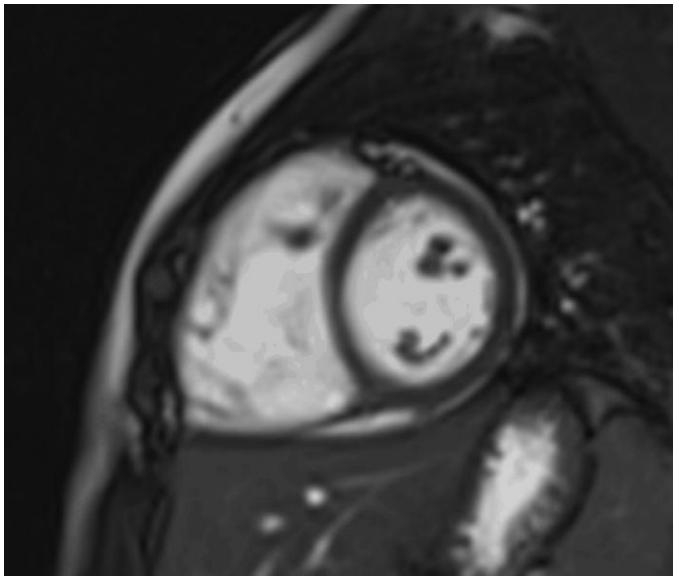
Dragulescu A, Int Am J 2012

Ebstein`s anomaly



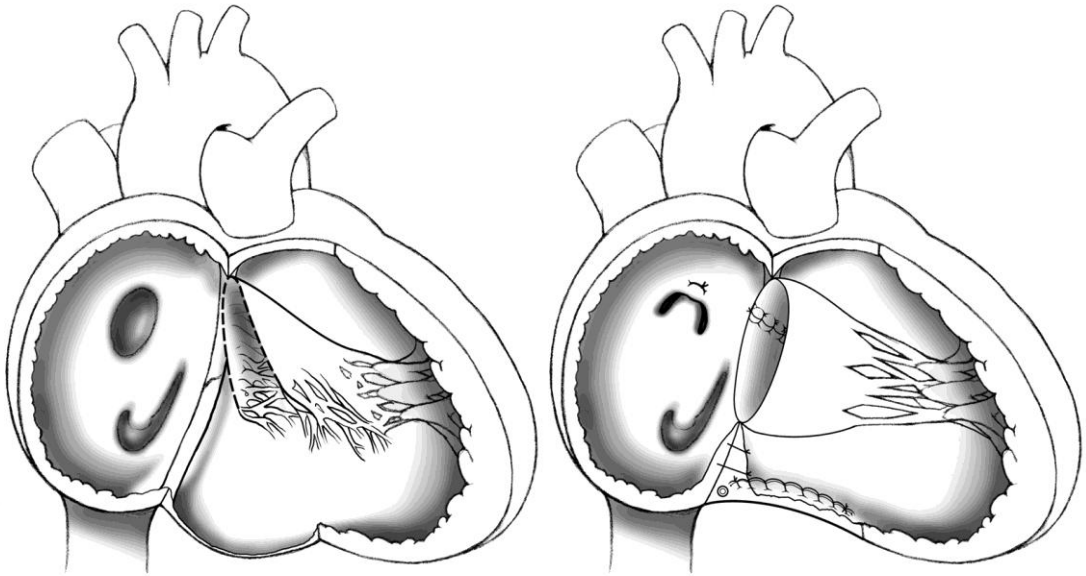






Ebstein`s anomaly: Cone operation

- Antero-Superior and Inferior leaflets mobilised and detached from their position in RV and rotated clockwise and sutured to the septal margin of AS leaflet (=cone)
- Septal leaflet (if present) delaminated and incorporated in cone
- Annuloplasty
- Right atrium and ventricle plicated and ASD closed (if present)



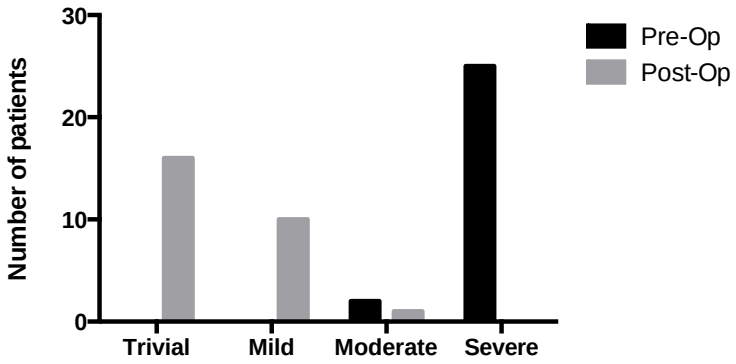
Da Silva JP, Arq Brasil Cardiol 2004, J Thor Cardiovasc Surg 2007

Cone reconstruction for Ebstein's anomaly: Patient outcomes, biventricular function, and cardiopulmonary exercise capacity

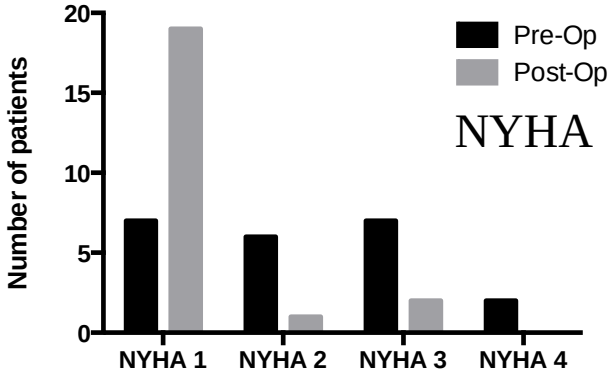
Michael Ibrahim, MD, PhD,[a,b] Victor T. Tsang, MD, FRCS,[a,b,c] Maryanne Caruana, MD,[d] Marina L. Hughes, DPhil, FRACP,[d,e] Synetta Jenkyns, BD,[e] Elodie Perdreau, MD,[e] Alessandro Giardini, MD,[c,e] and Jan Marek, MD, PhD[c,e]

JCVTS 2014

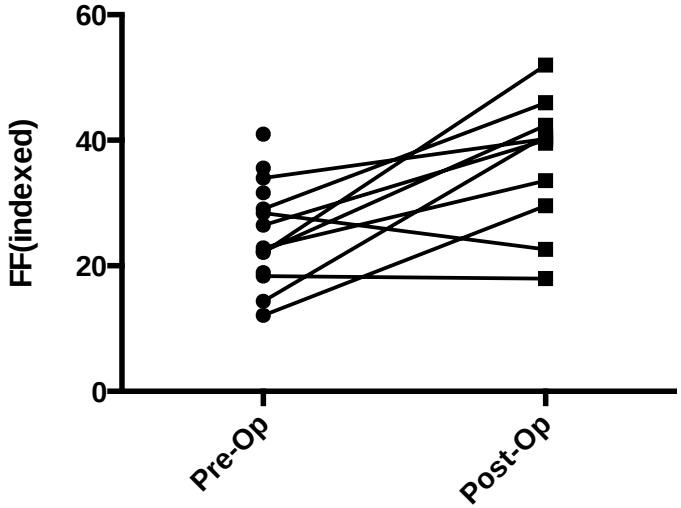
Reduction of TR



Improved functional status

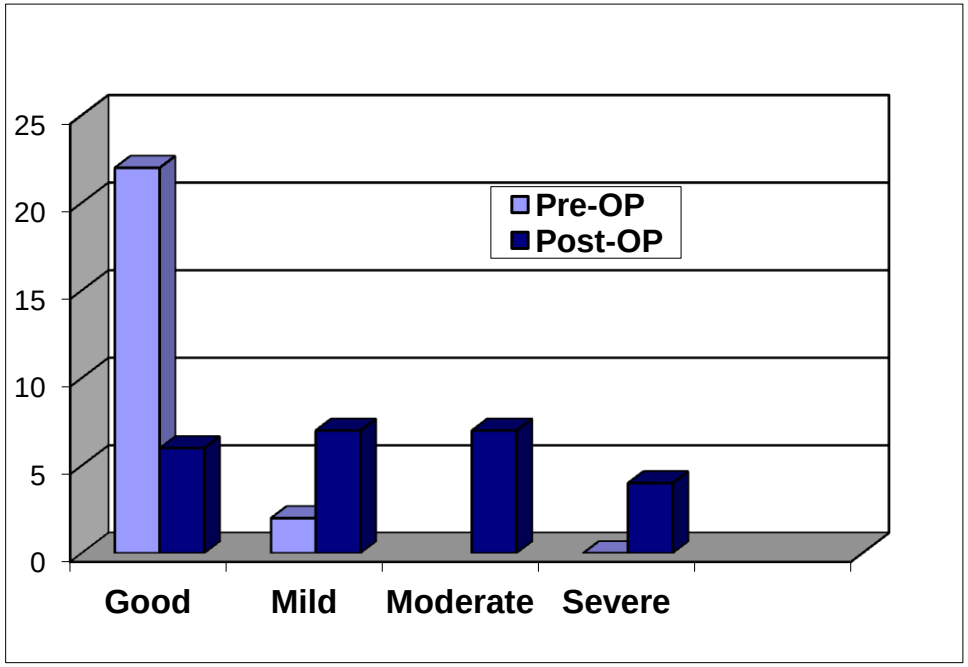


Increased forward flow

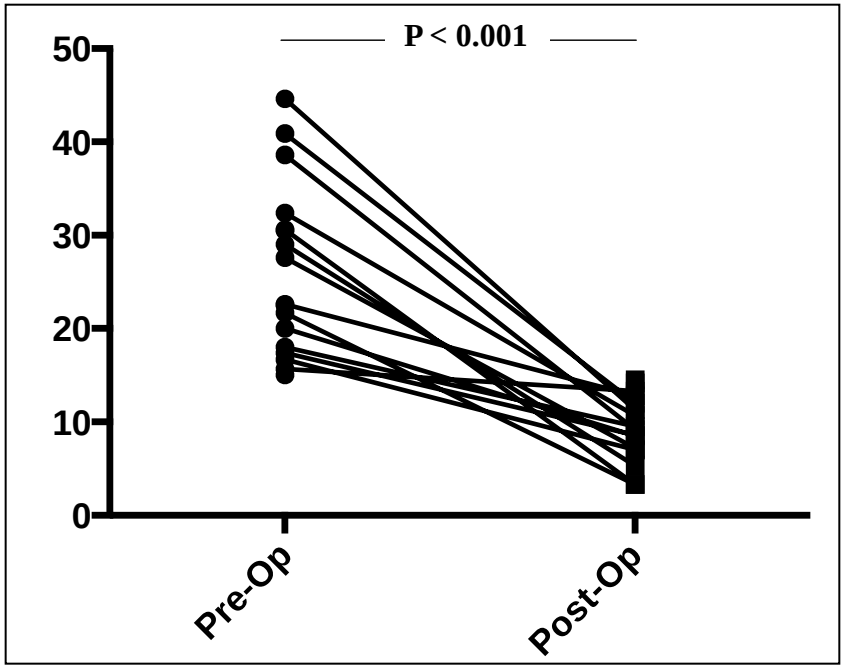


….but, despite clinical improvement, markedly reduces RV function …!?

ECHO: eyeballing

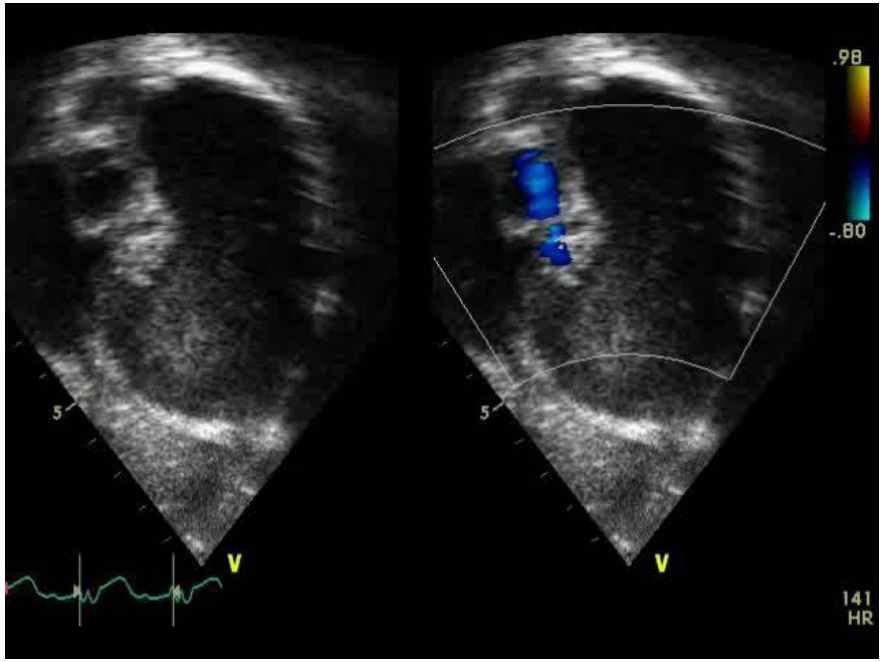


ECHO: TAPSE



Ebstein`s anomaly: Cone operation

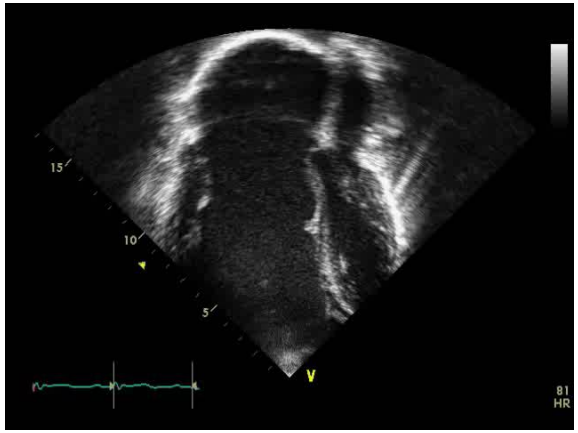
Day 1	Day 6	Day 14
Post cone	Discharged	Post cone



Parental consent

Why does RVEF decrease after surgery?

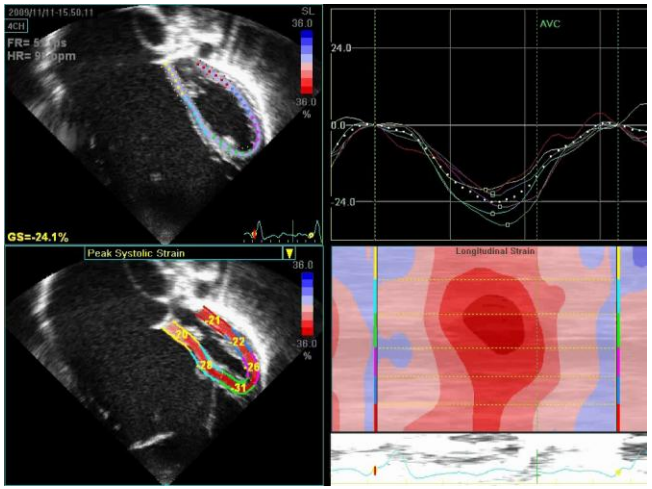
Pre-operative	Post-operative	
	1 week	4 years



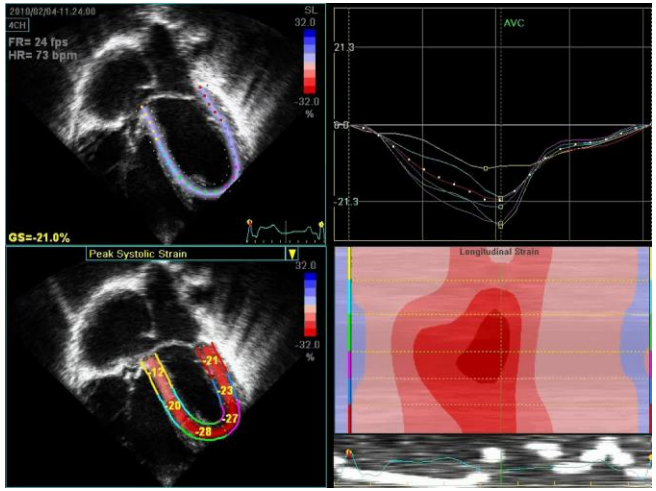
- **Competent valve**
  -Decreased stroke volume & ejection fraction
  -Increased afterload
- **“Re-ventricularised” myocardial wall**
- **Remodelation** or **Intrinsic Cardiomyopathy**?

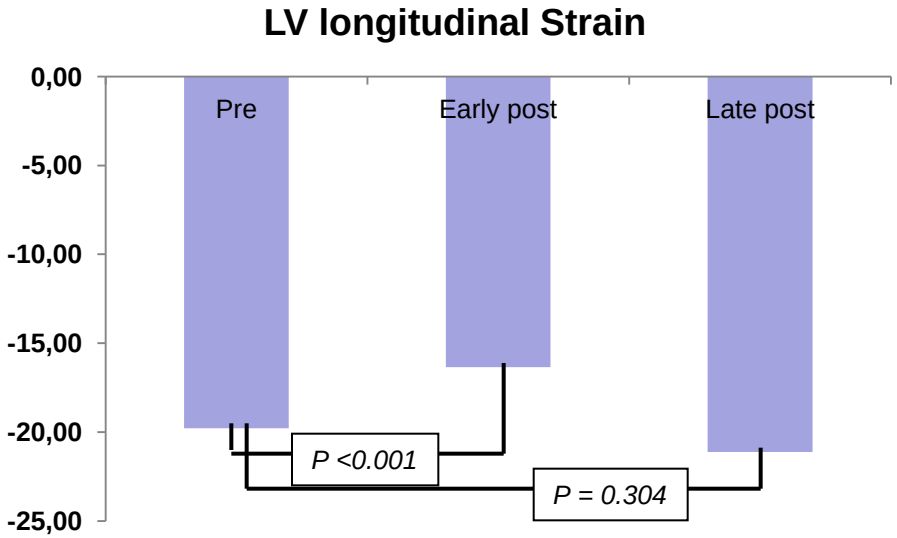
Ebstein's: LV function

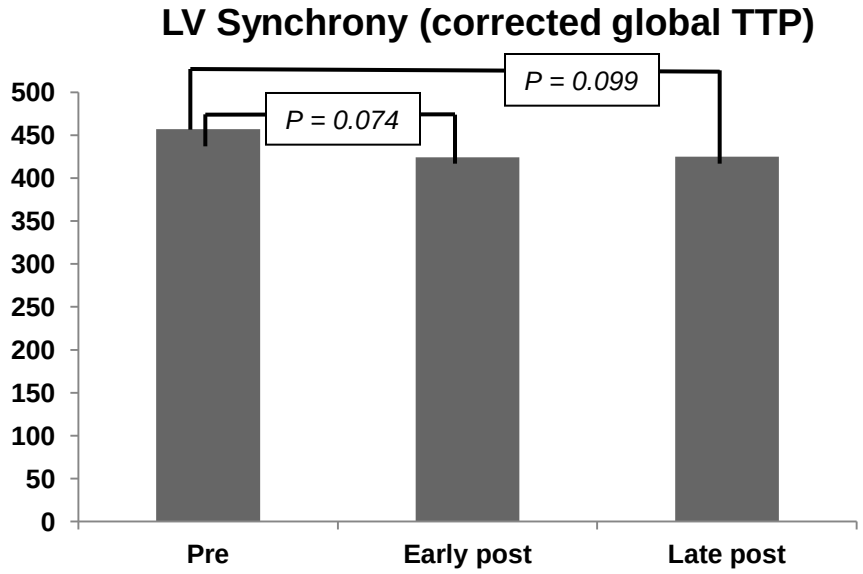
Before Cone



After Cone







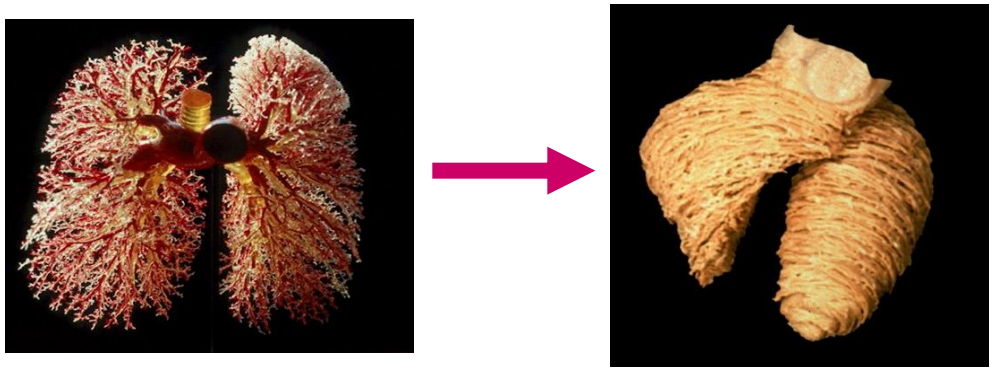
Perdreau E, GOSH 2016

Right Ventricle

Exposed to High Atferload

Implication of increased PVR

….however, it is integrity of RV function, rather than degree of vascular injury, that is major determinant of symptoms and survival in PAH



Kelly M, 2005

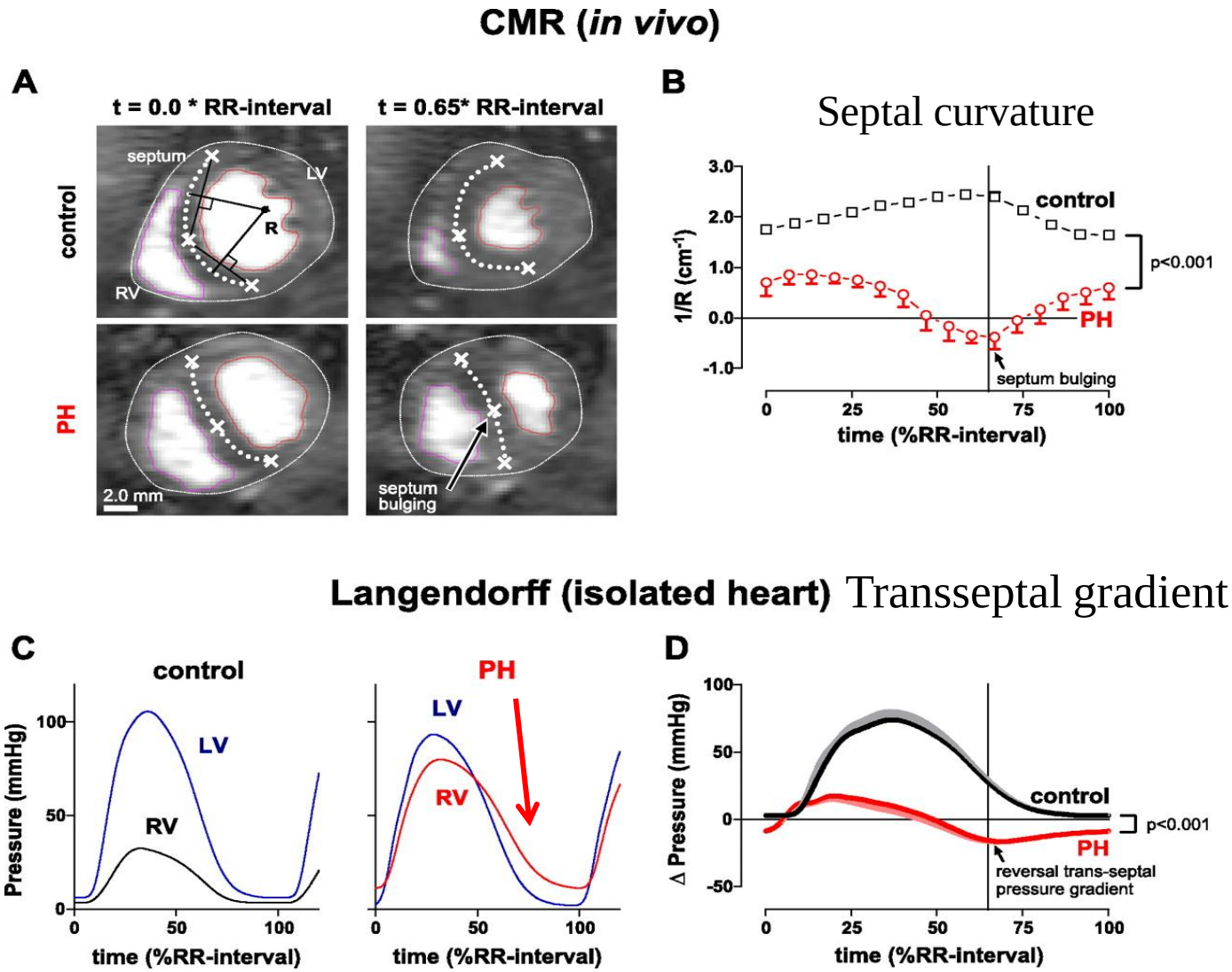
Outcome is predominantly determined by the response of the RV to increased afterload

D'Alonso GE et al. 1991

Sandoval J et al. 1994

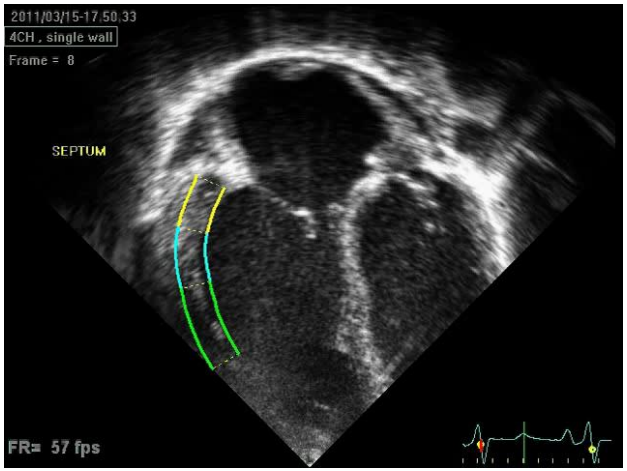
Bogaard HJ et al. 2009

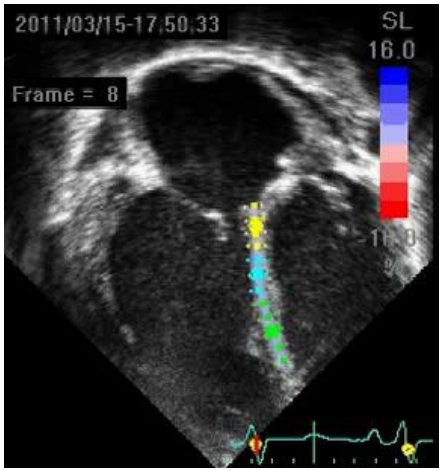
PH-related ventricular dyssynchrony in Experimental model (monocrotaline-treated rats)

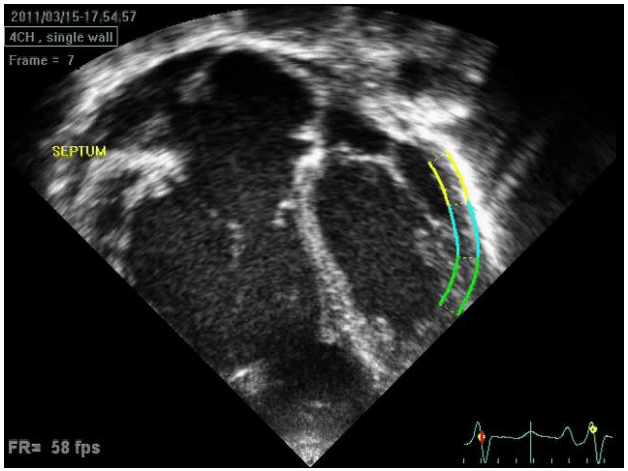


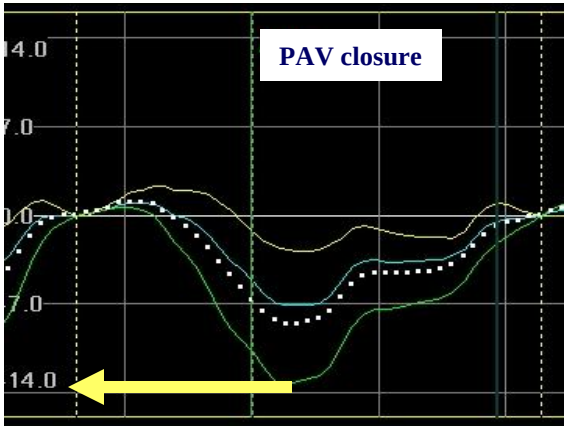
Handoko M L. Am J Physiol Heart Circ Physiol 2009

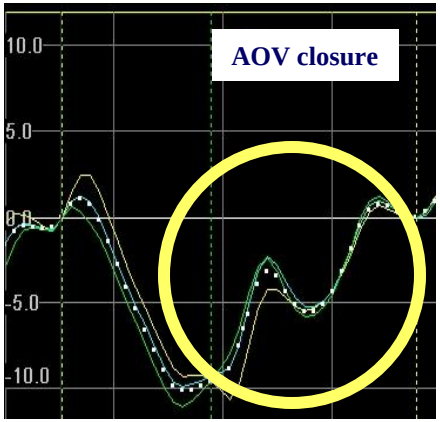
RV dyssynchrony & RV-LV interaction in PAH

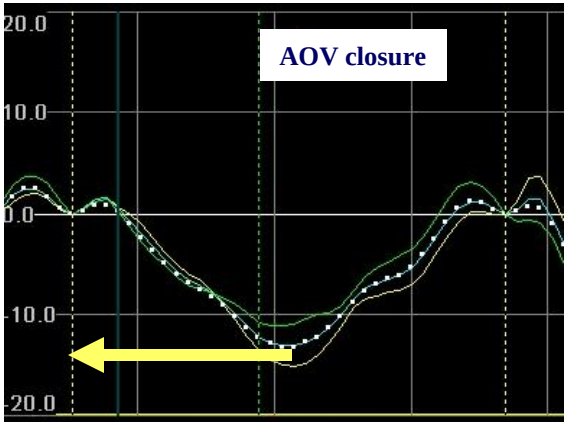






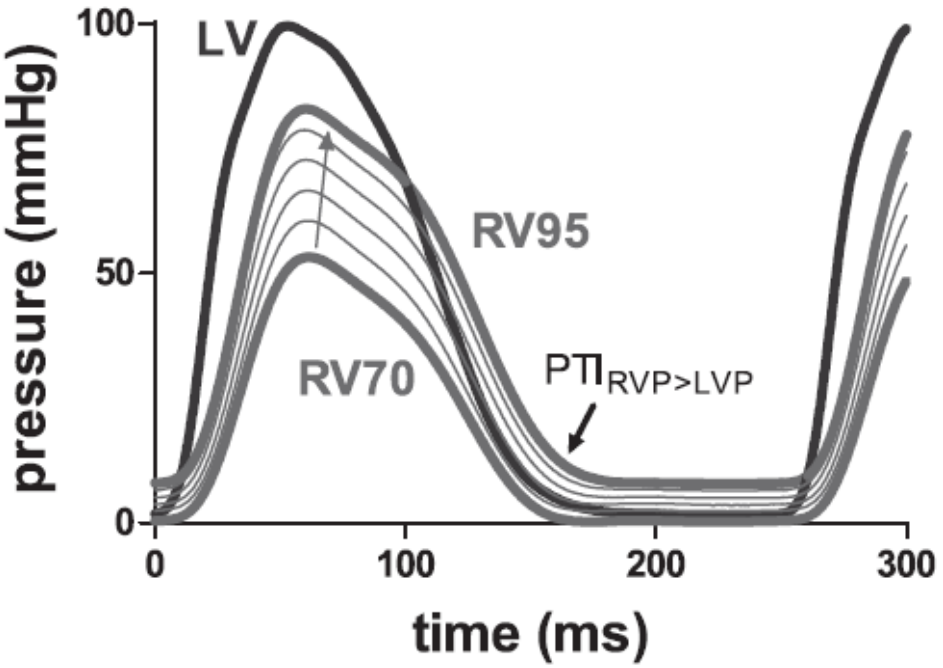


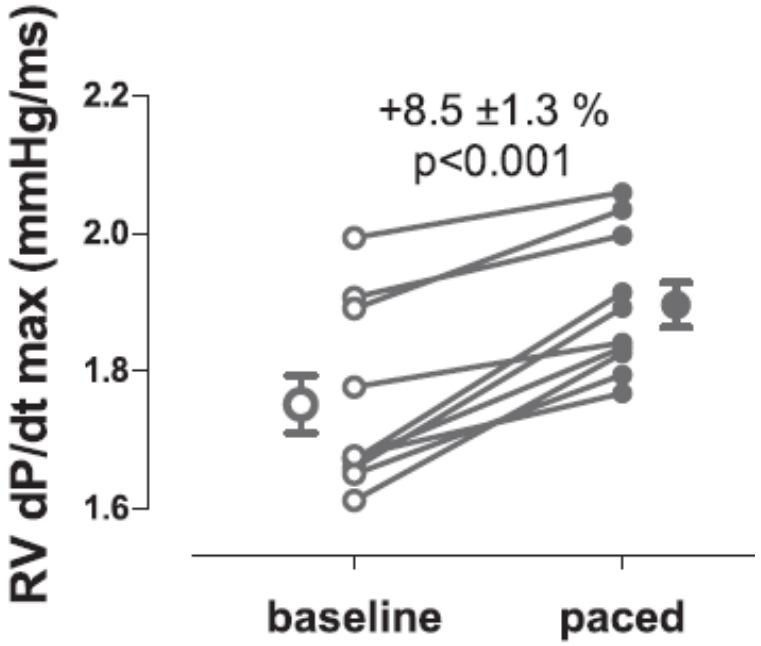




Important intra- (RVFW and IVS) &
inter-ventricular (RVFW and LVFW) mechanical delay

PH-related ventricular dyssynchrony in Experimental model (monocrotaline-treated rats)

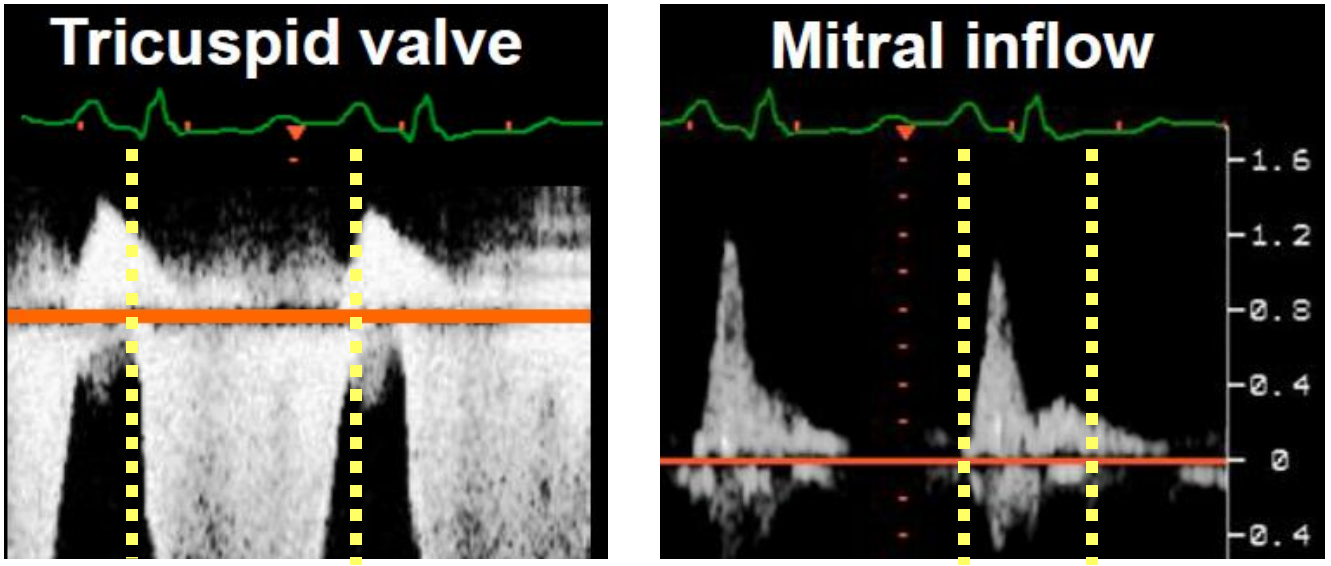




Handoko M L. Am J Physiol Heart Circ Physiol 2009

RV dyssynchrony & RV-LV interaction in PAH

S:D Ratio (afterload independent)



Friedberg M, JASE 2007

- Correlated with worse outcome, exercise tolerance, haemodynamics and pulmonary resistance
- Associated with risk for lung transplantation or death (hazard ratio 1.13, p <0.001).

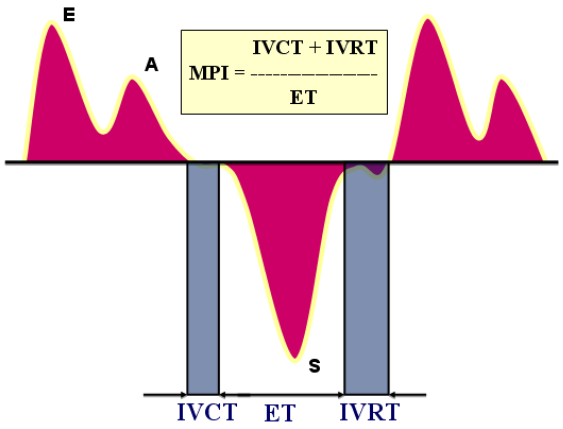
Alkon J, Am J Cardiol 2010

RV dyssynchrony & RV-LV interaction in PAH

Myocardial Performance Index

Heart rate independent

Afterload independent

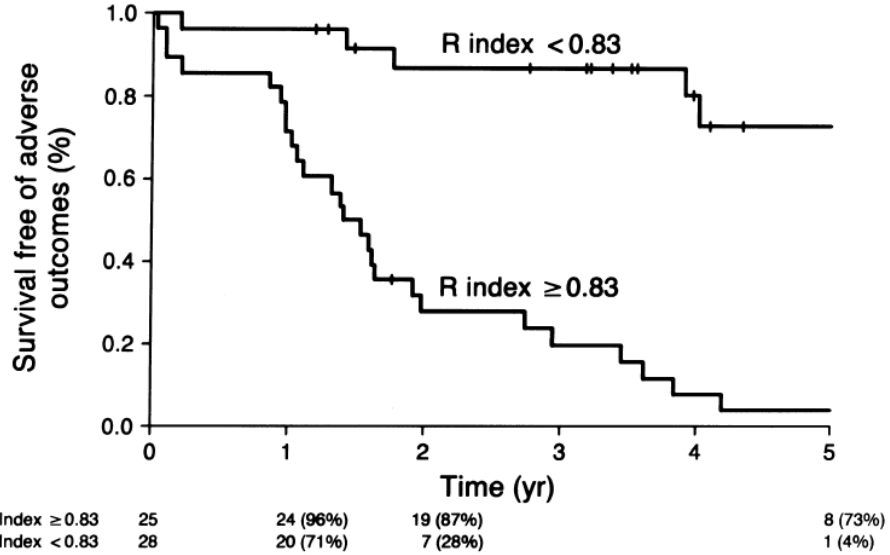


N = 0.39 ± 0.05 (LV)

N = 0.28 ± 0.04 (RV)

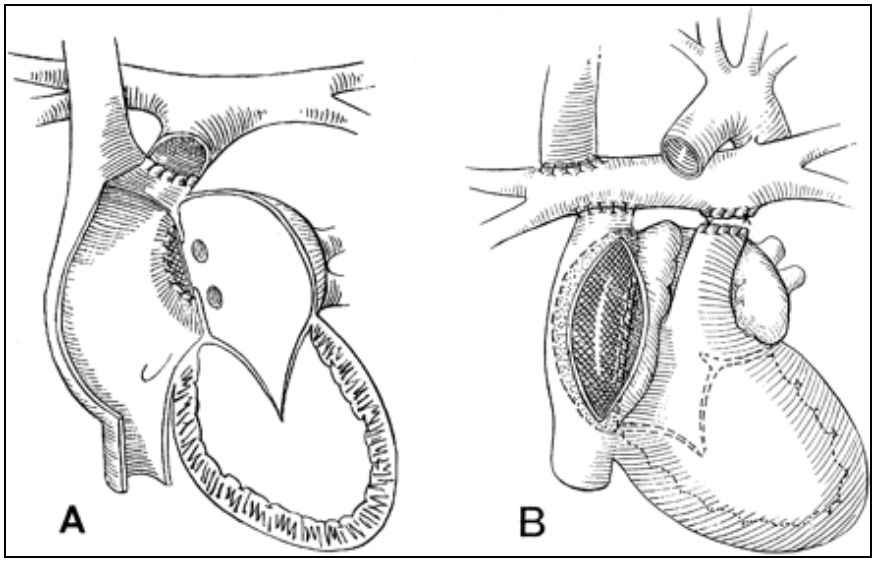
Tei C, J Cardiol 1995

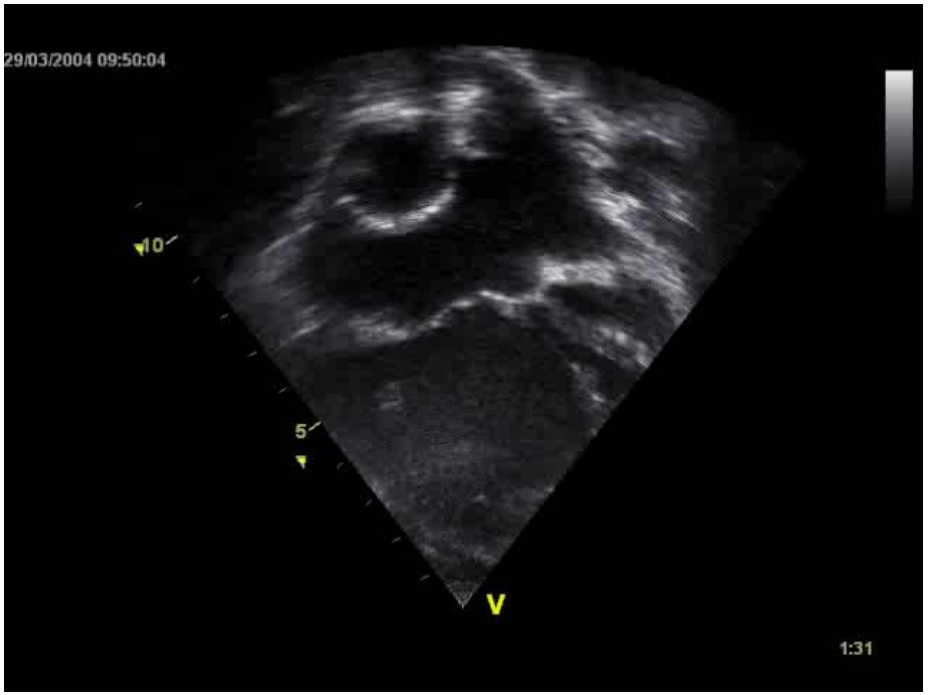
Pulmonary Hypertension

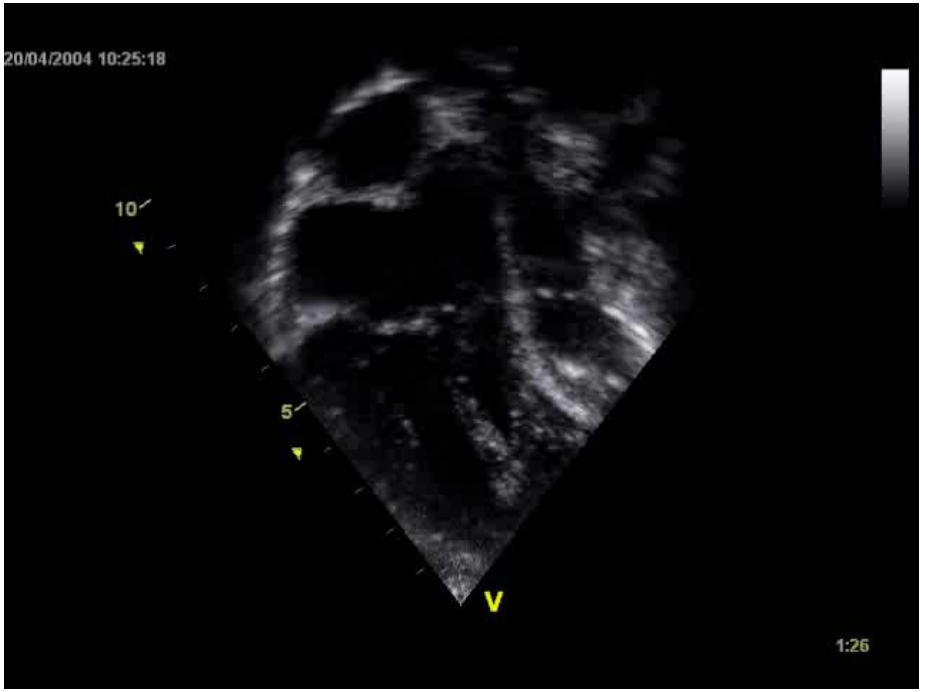


Zimbarra Cabrita I Eur J Echo 2010

Fontan







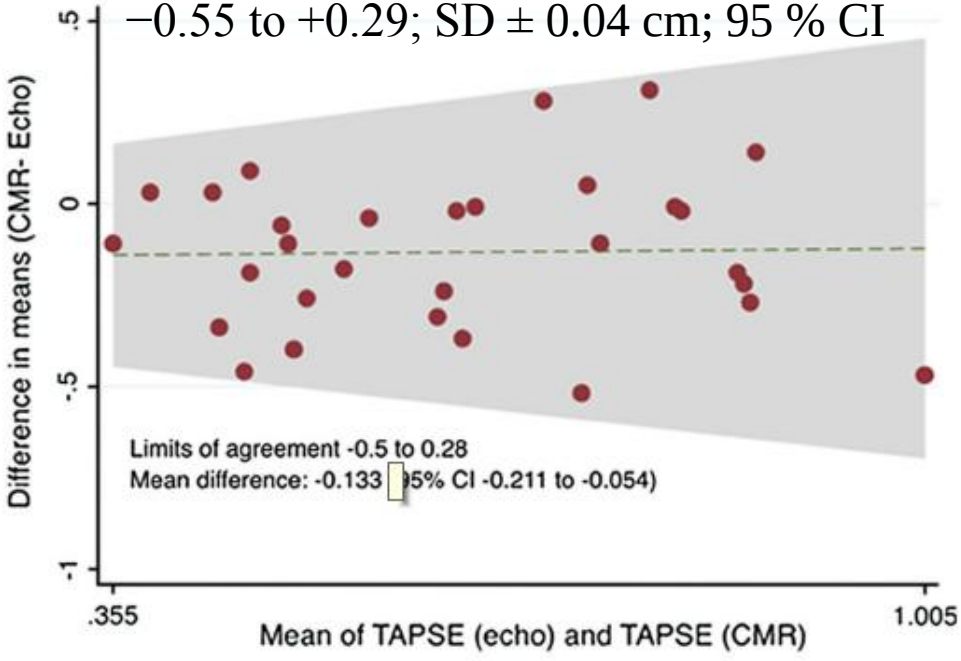
RV function in HLHS: TAPSE (ECHO & MRI) post Fontan completion

- TAPSE *z*-scores were **decreased in all** (29) −8.7 ± 1.0

No association between

- TTE–TAPSE and RVEF ($p = 0.83$)
- TTE–TAPSE *z*-score and RVEF ($p = 0.83$)
- MRI-TAPSE and RVEF *(p=0.67)*

Good limits of agreement:
−0.55 to +0.29; SD ± 0.04 cm; 95 % CI

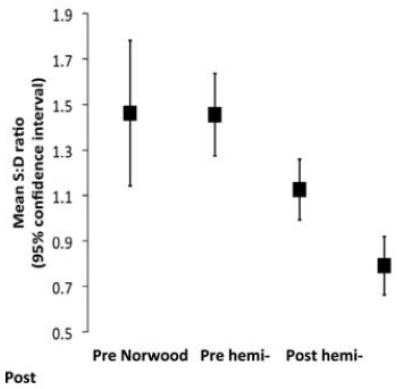


TAPSE is not a surrogate for RVEF

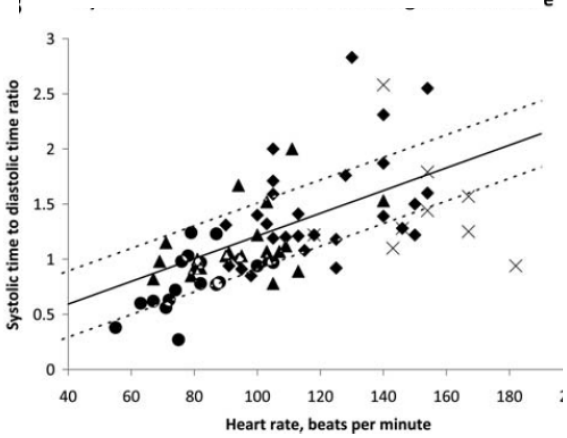
Avitabile CM (CHOP), Pediatr Cardiol 2014

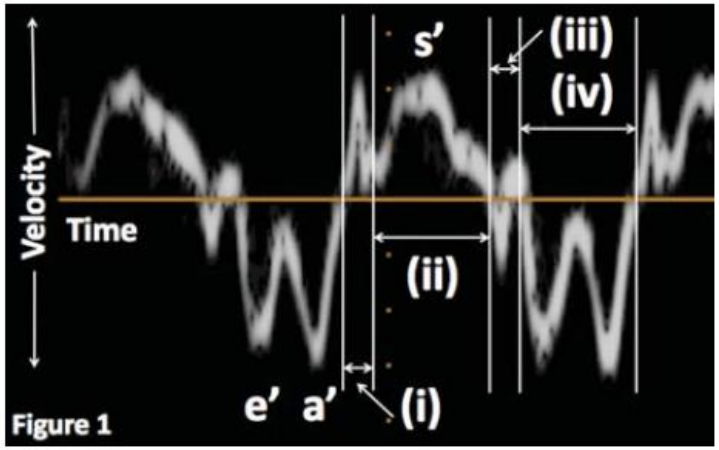
Myocardial TDI time derived indices

S/D ratio in different Fontan stages



S/D ratio against HR

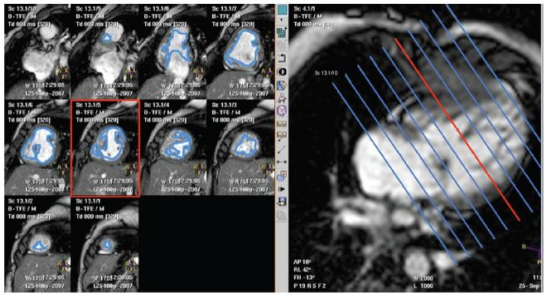


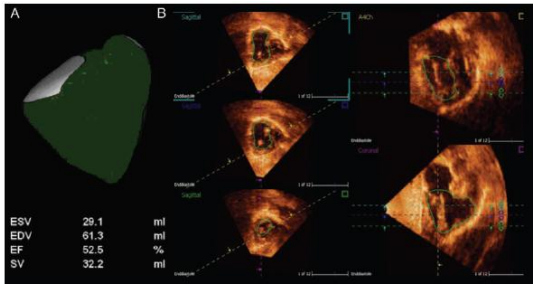


- S/D ratio between surgical stages can be accounted for by heart rate alone
- MPI is elevated across all surgical stages due to the prolonged IVCT and IVRT
- **Neither MPI z-score nor S:D ratio significantly correlated with MRI**

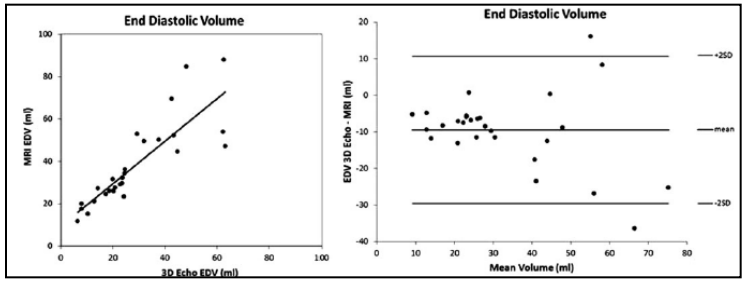
Bellsham-Revell HR, EHJ-CVI 2012

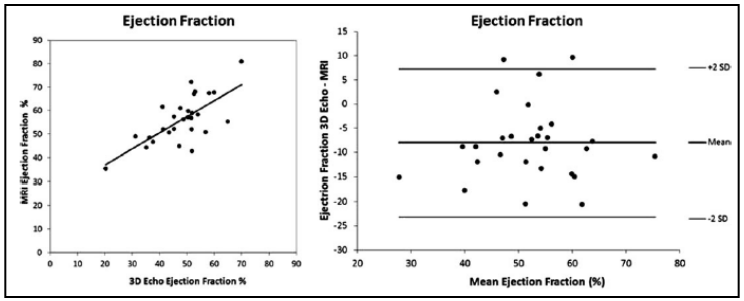
HLHS (MRI gold standard?)





	3D echocardiogram Median (mL) (range)	CMR Median (mL) (range)	Correlation *R* value	*P*-value
EDV	23 (6.5–63.2)	30.6 (11.8–87.9)	0.85	<0.0001
ESV	12.6 (3.7–37.0)	14.9 (5.8–33.9)	0.84	<0.0001
SV	11.2 (2.8–33.0)	17.1 (6.0–54.1)	0.83	<0.0001
EF %	48.2% (31.2–64.9)	56.5% (42.7–72.2)	0.70	<0.0001





3D ECHO Underestimates

- End-diastolic volumes
- End-systolic function
- Ejection fraction
- Stroke volume

Bell A, EHJ-EACVI 2014

RV function

- All parameters/indices sensitive to loading conditions
- Several indices (MPI, S:D) applicable with high predicting value where RV exposed to high afterload supports biventricular circulation
- No parameter applicable for RV supporting univentricular circulation (eyeballing/FAC/MRI)
- Ventricular interdependence has major impact on pump efficiency

  - CRT? PA/AO band? ↑SVR?


GOSH