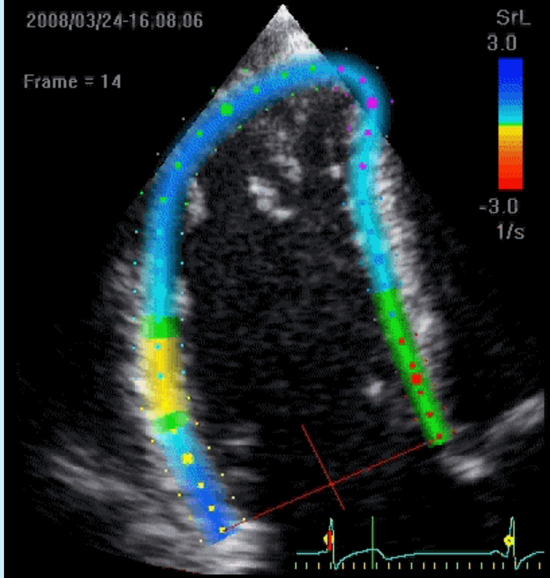

RV and pulmonary circulation during exercise

EAE Teaching Course

Sofia, Bulgaria 2012

Dr André La Gerche

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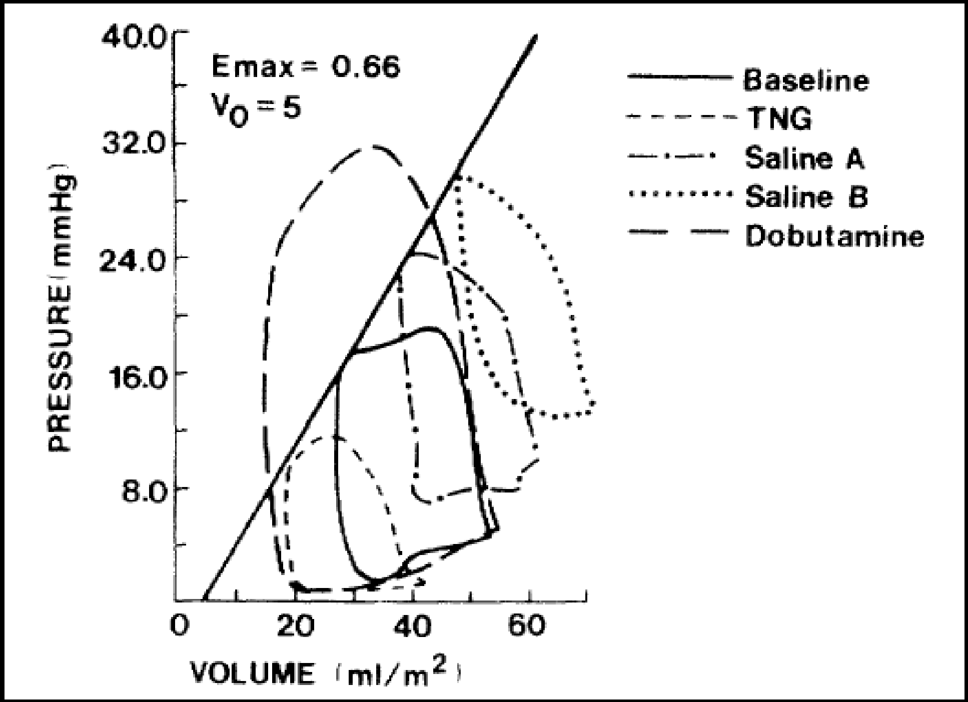
Disclosures: none

RV function is most relevant when the RV has to work

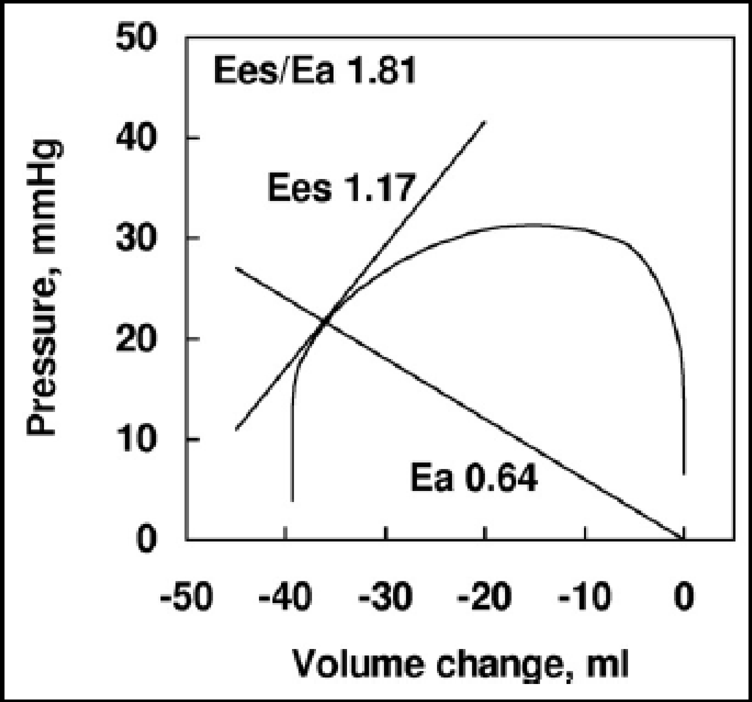
1. Pathological load
   - Increased afterload due to LV dysfunction
   - Pulmonary vascular disorders
   - Chronically increased preload

2. Activity, exercise, exertion
   - Increased RV wall stress
   - Increased RV work
   - Increased O_2 demand

The healthy RV at rest
- it doesn't need to do anything



Brown and Ditchey *Circulation* 1988



Pagnamenta, Naeije et al.
J Appl Physiol 2010

The LV does **not** do all of the work

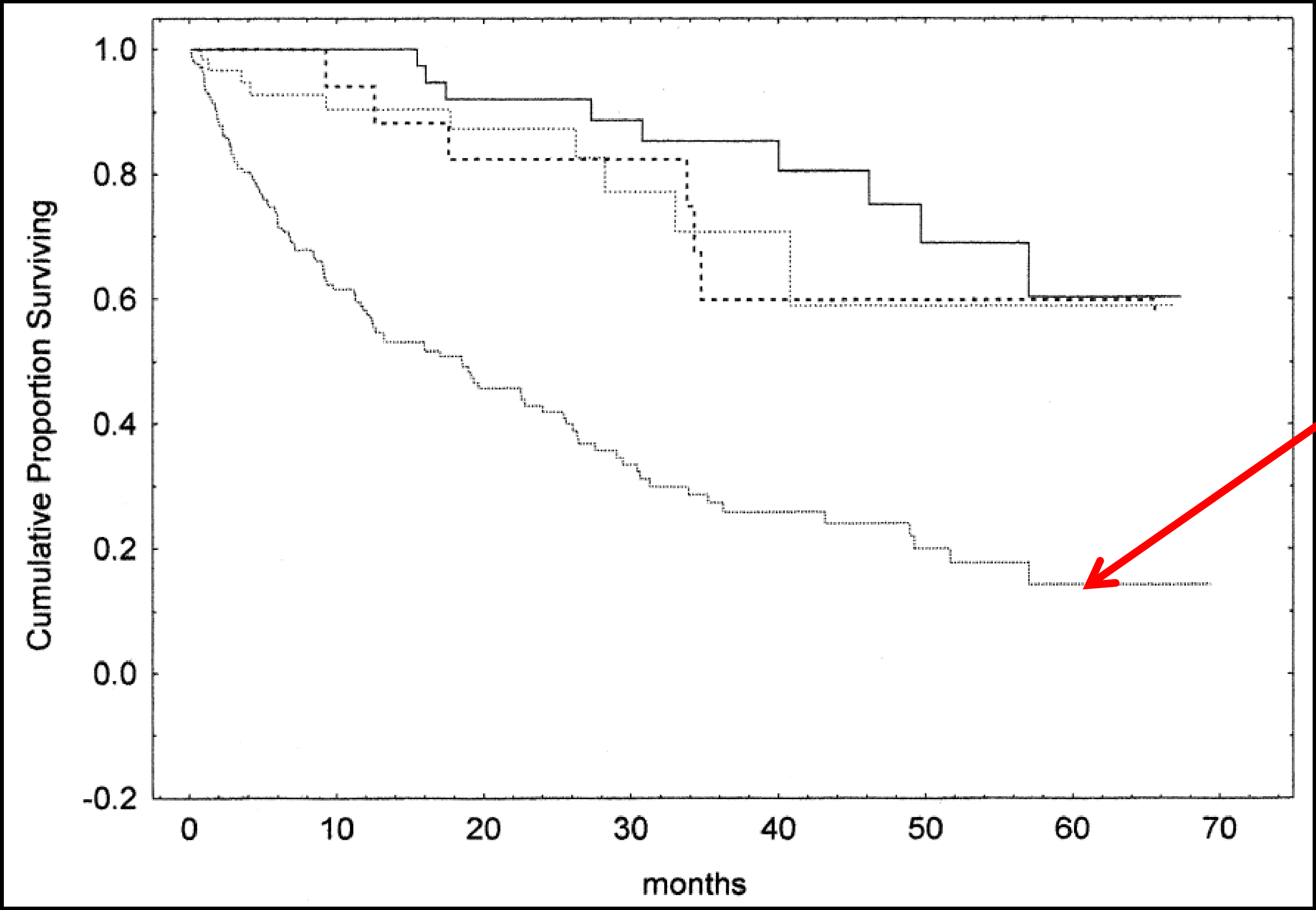
- Potentially misleading conclusions:
  - LV contributes substantially to RV pressure generation (Seki 1975, Yamaguchi 1991, Feneley 1995)

BUT

- When RV afterload is increased then, in the absence of a functional RV, CO rapidly falls (J Hoffman Thorac Cardiovasc Surg 1994)

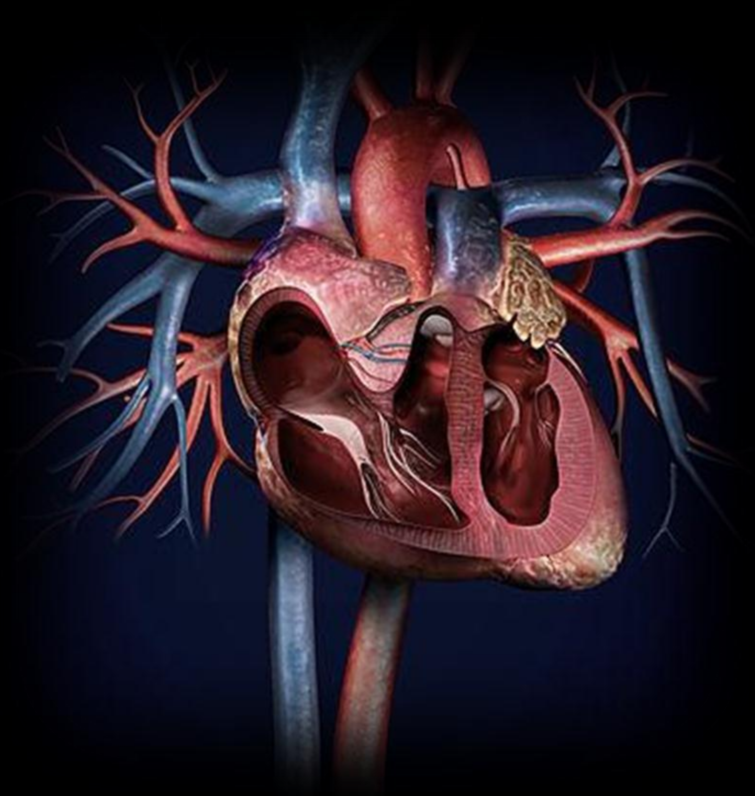
Independent and Additive Prognostic Value of Right Ventricular Systolic Function and Pulmonary Artery Pressure in Patients With Chronic Heart Failure

Stefano Ghio, MD, FESC,* Antonello Gavazzi, MD, FESC,* Carlo Campana, MD,* Corinna Inserra, MD,* Catherine Klersy, MD,† Roberta Sebastiani, MD,* Eloisa Arbustini, MD,‡ Franco Recusani, MD,* Luigi Tavazzi, MD, FESC, FACC*

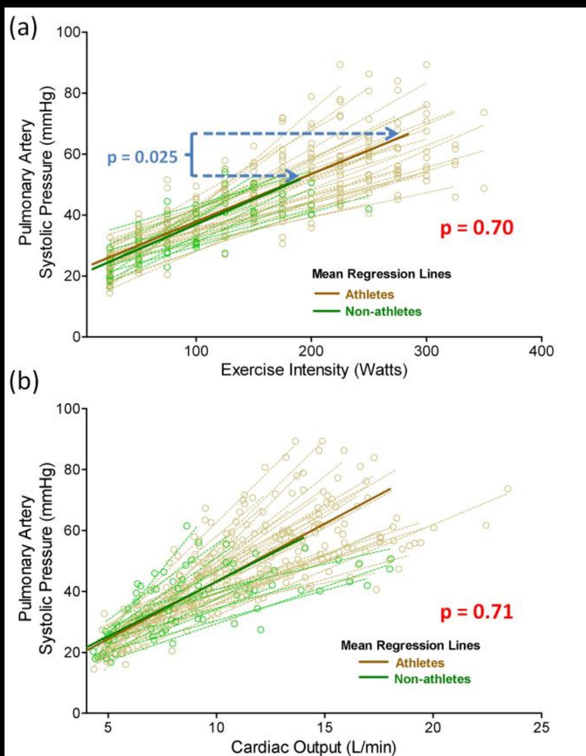


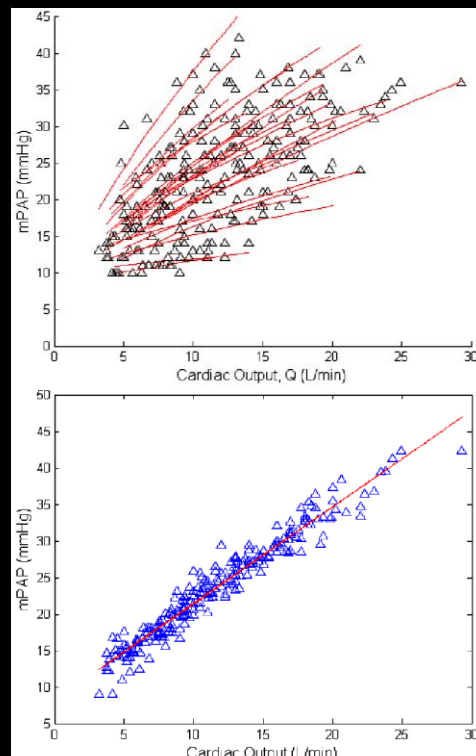
JACC 2001

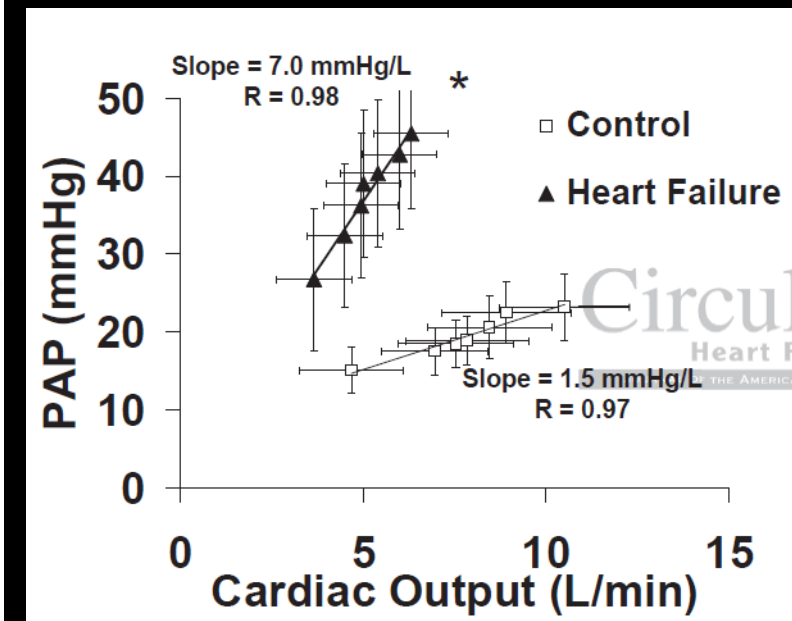
Why do we have a right ventricle?



Exercise = RV work







La Gerche, Prior et al.
J App Physiol 2010

Argiento, Naeije et al.
Eur Resp J 2010

Lewis, Semigran et al.
Circ Heart Failure 2011

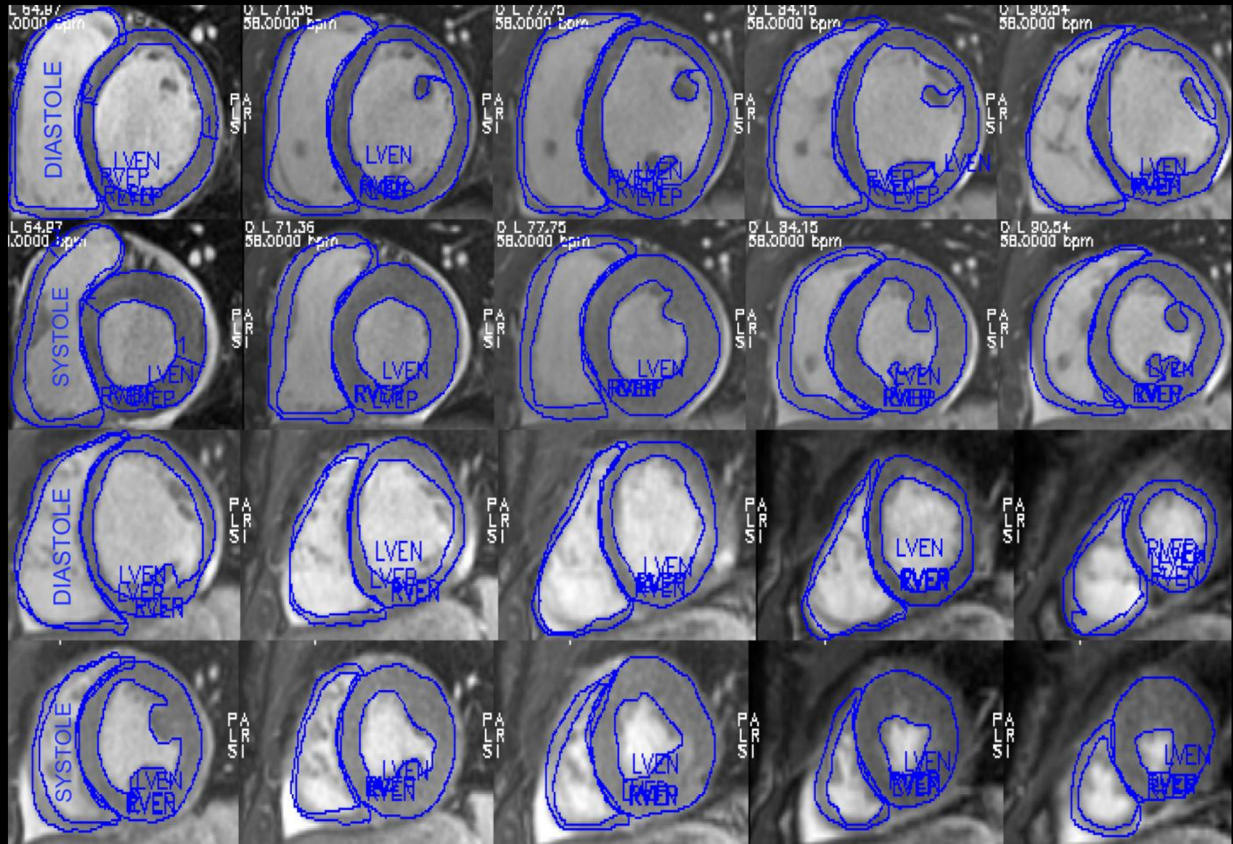
Investigating ventricular hemodynamics during exercise

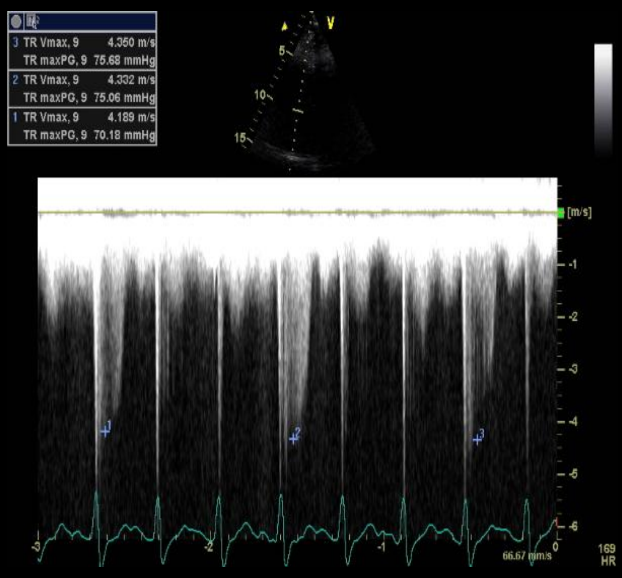
- ***Echocardiography***
  - Volumes
  - Cardiac Output
  - Pulmonary artery pressures
- ***Cardiac MRI***
- ***Radial arterial catheter***

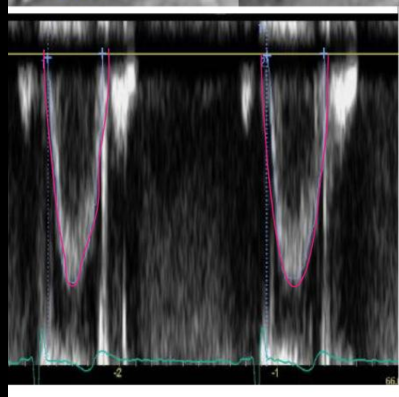
Measuring wall stress

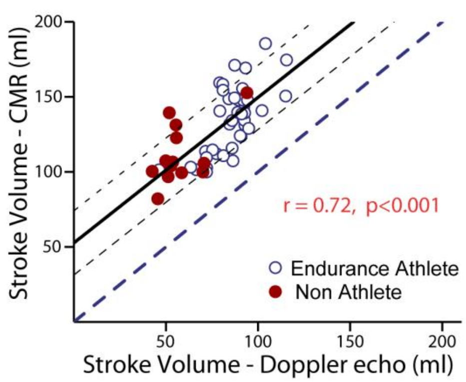
Hybrid technique

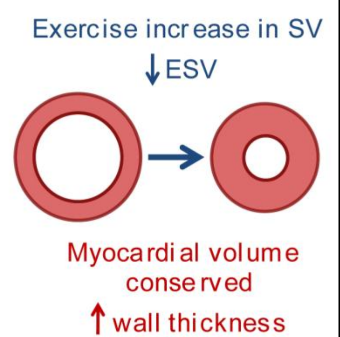
- Volumes and mass from CMR
- Change in volumes from echo VTI
- Pressures
  - SBP: arterial line
  - PASP: echo



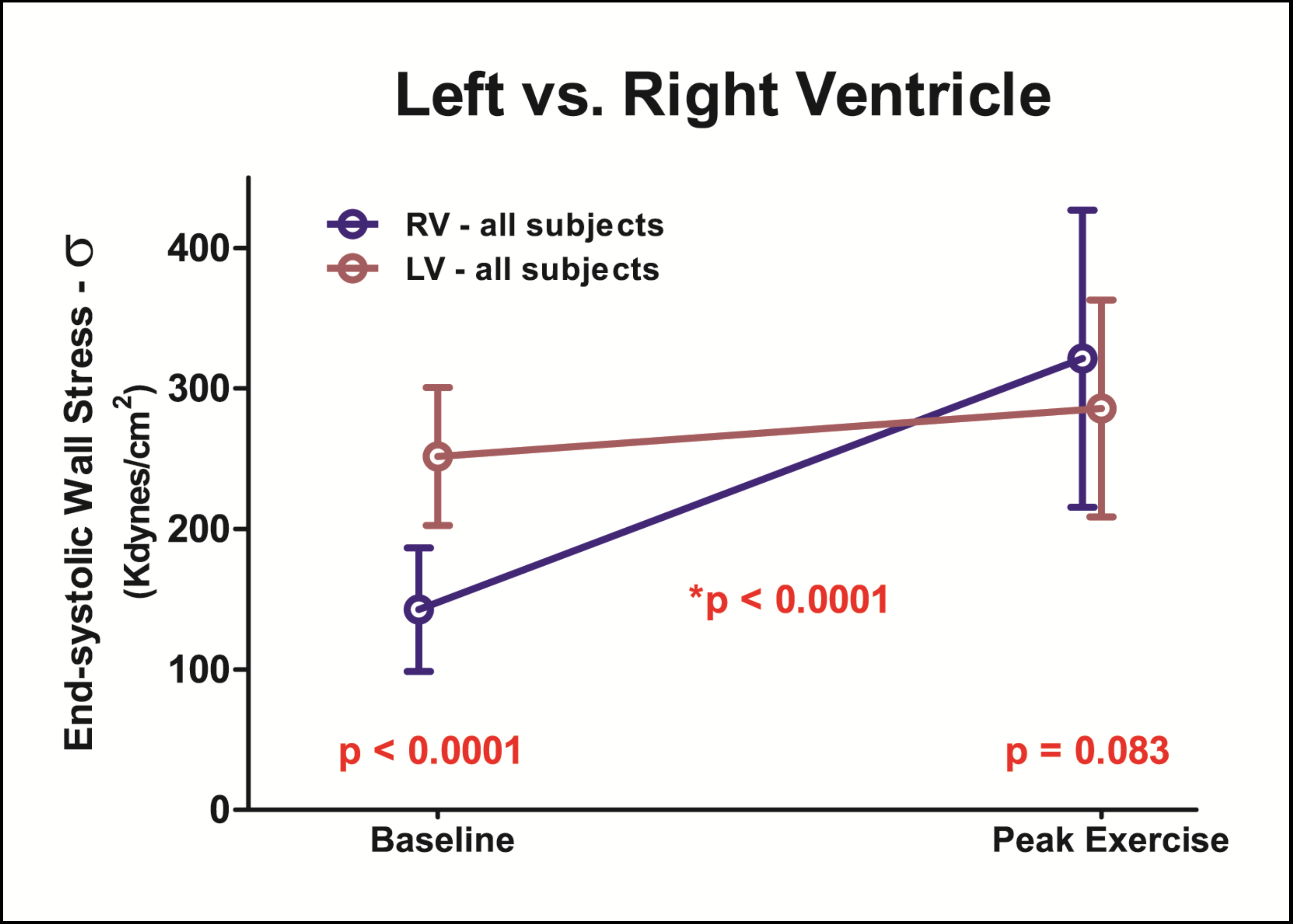








Change in wall stress with exercise

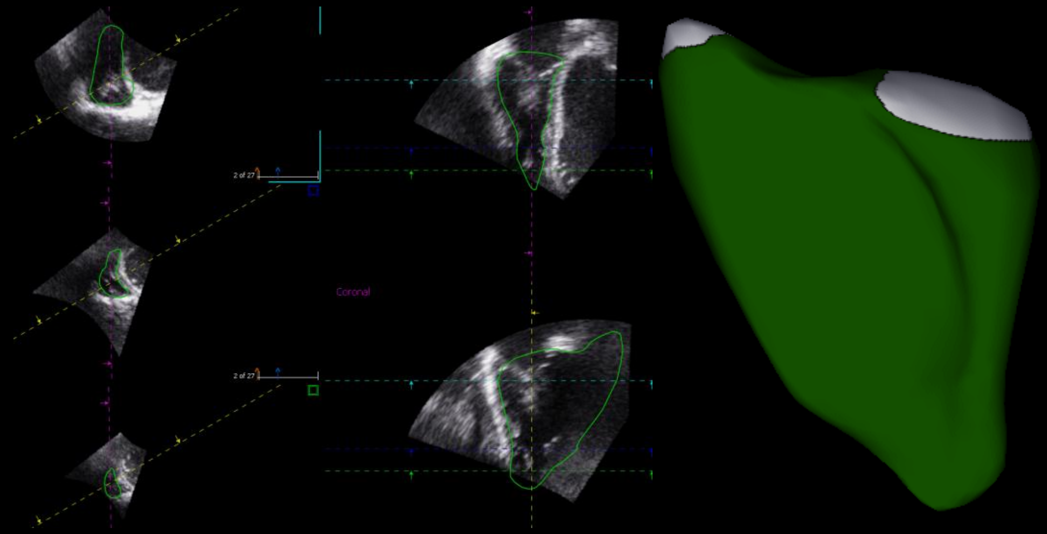


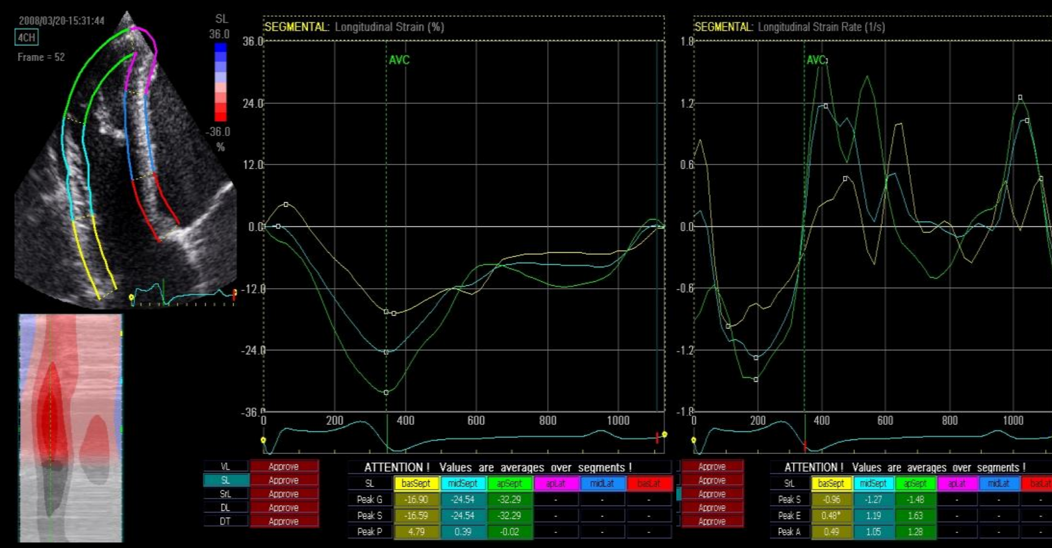
La Gerche et al. *Med Sci Sports Exerc.* 2011

...and after 8 hours

Methods - echocardiography

- <u>3D Echo (GE Vivid 7)</u>
  - LV and RV full volume acquisitions
  - TomTec software
  - Validated against CMR
- <u>Strain and SR imaging</u>
  - 2D speckle tracking
  - RV and LV separately
  - 60 -90 frames per second
- <u>Traditional</u>
  - RV Fractional Area Change
  - Tricuspid Annular Plane Systolic Excursion





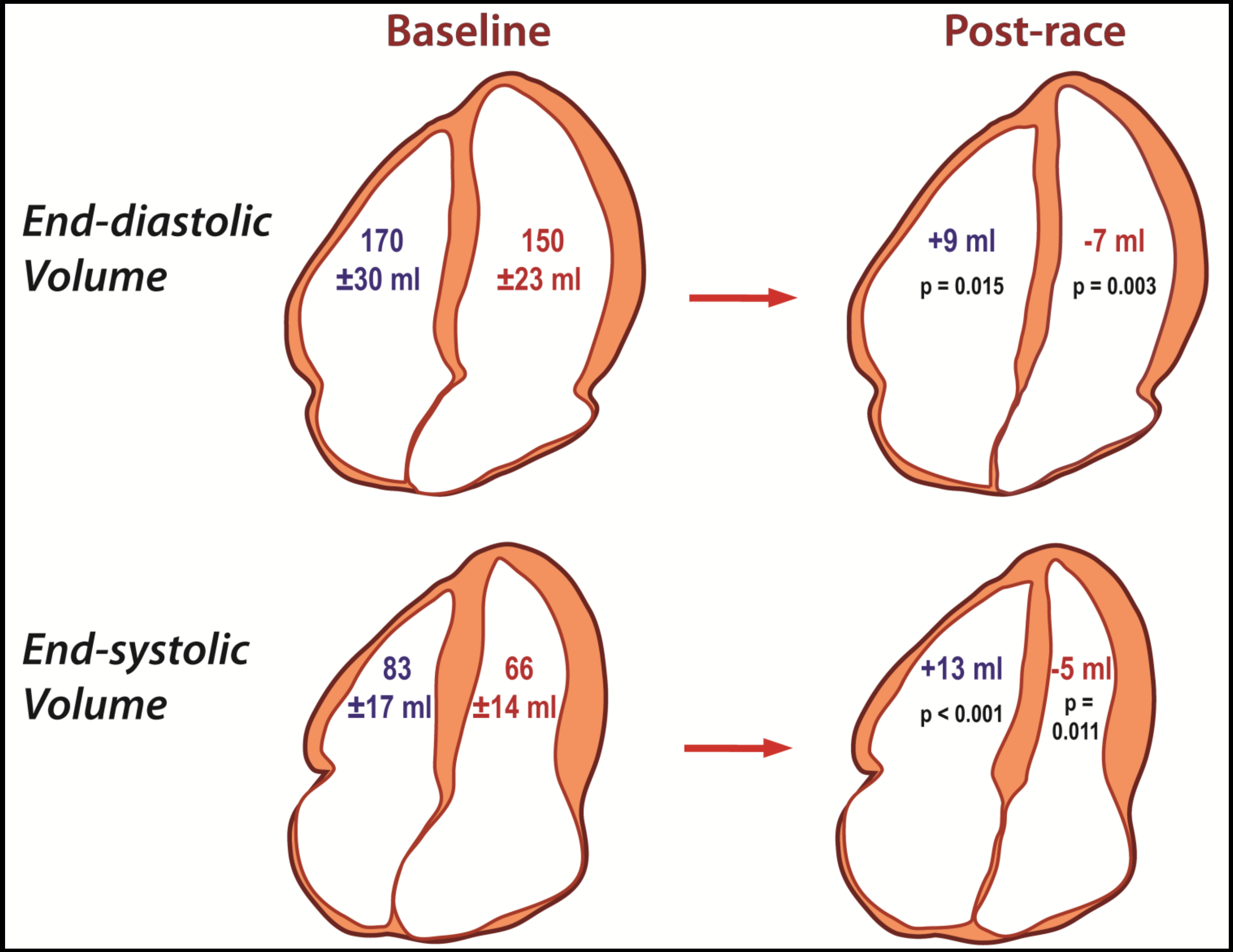
Results: RV but not LV dysfunction

	Baseline	Post-race	Follow-up	p-value
Right Ventricular Measures				
RVEF (%)	51.0 ± 3.6	46.4 ± 6.5	50.0 ± 3.8	<0.0001
RVFAC (%)	51.5 ± 6.0	44.3 ± 11.2	49.8 ± 6.6	<0.0001
TAPSE	24.9 ± 3.9	24.0 ± 4.5	26.5 ± 4.1	0.035
RV strain (%)	27.2 ± 3.4	23.7 ± 3.7	25.6 ± 3.0	0.001
RV SRs (s^{-1})	1.42 ± 0.24	1.26 ± 0.23	1.29 ± 0.19	0.008
Left Ventricular Measures				
LVEF (%)	56.4 ± 5.2	57.5 ± 5.6	58.8 ± 5.1	0.147
LV strain (%)	18.4 ± 3.7	16.9 ± 2.8	17.7 ± 2.3	0.071
LV SRs (s^{-1})	0.98 ± 0.26	0.95 ± 0.15	0.89 ± 0.13	0.13

***ALL* RV measures decreased whilst *NO* LV measures changed**

La Gerche, Heidbuchel, Prior et al. Eur Heart J In Press

RV ***dilates*** whilst the LV ***shrinks***



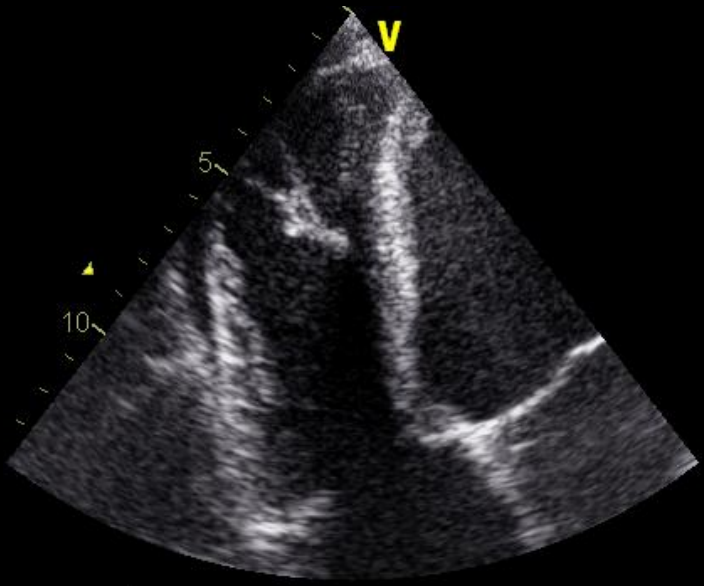
La Gerche, Heidbuchel, Prior et al. Eur Heart J In Press

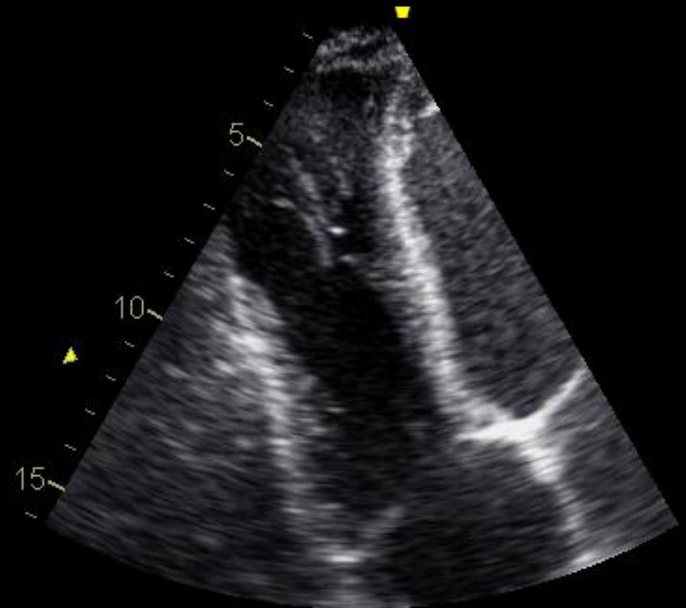
Effect of prolonged intense exercise on the RV

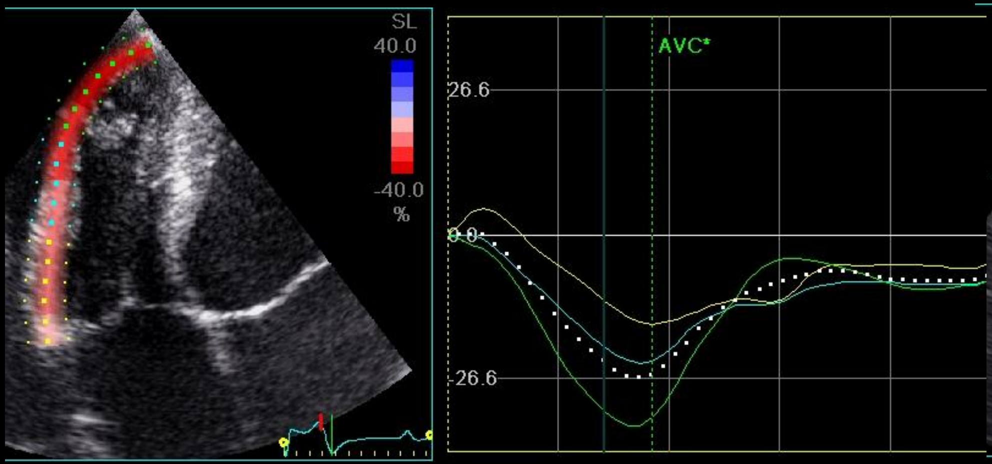
Pre

Post

Effect of prolonged intense exercise on the RV



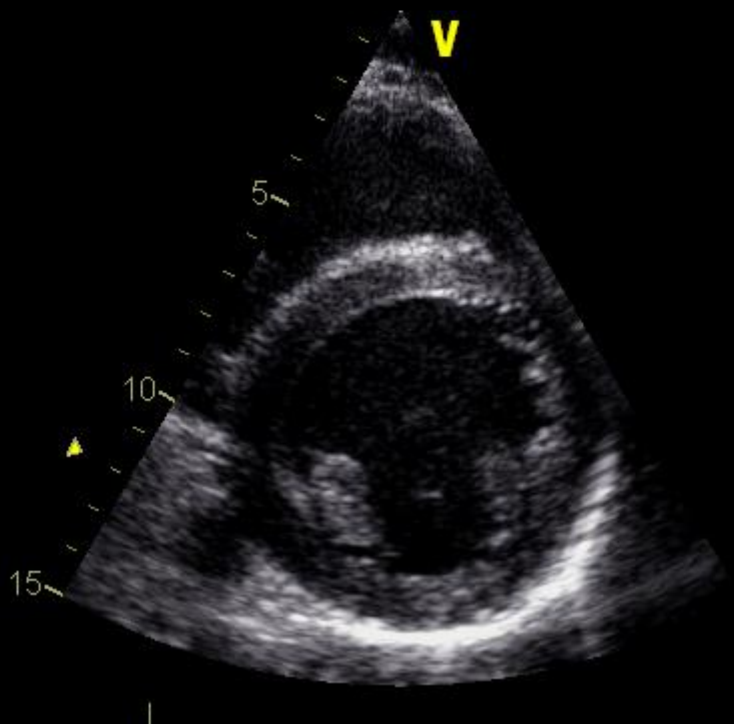




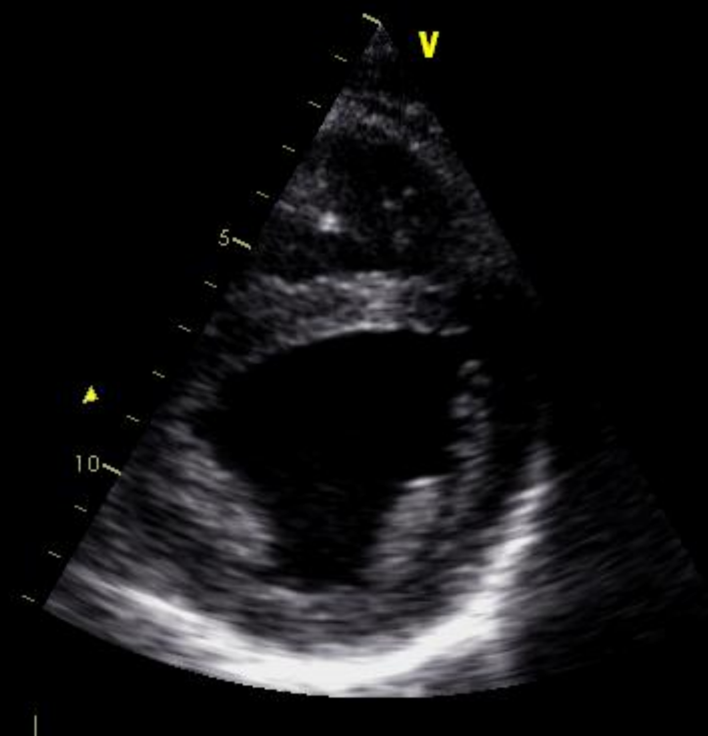
Pre

Post

Effect of prolonged intense exercise on the RV



Pre



Post

The RV

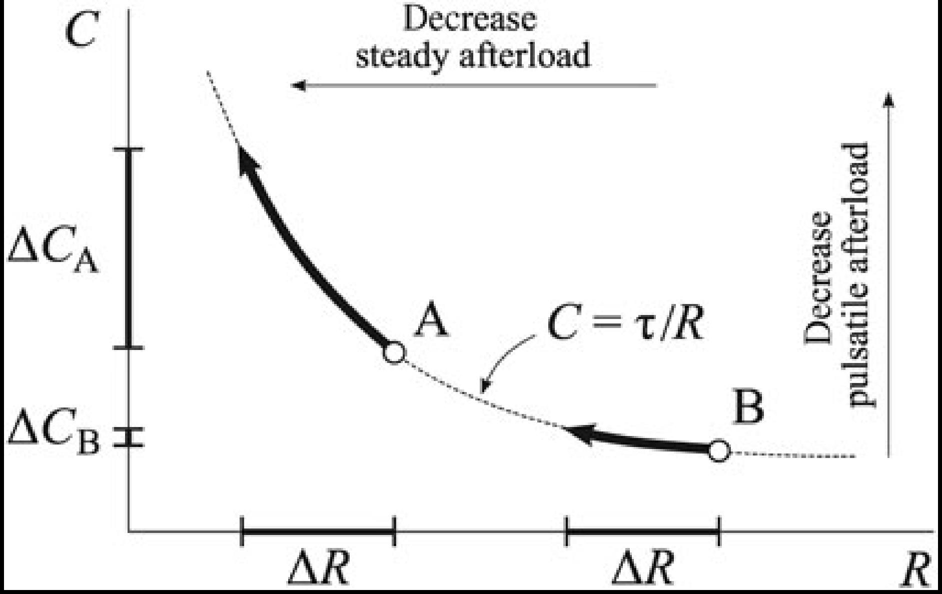
"the *Achilles heel* of the exercising heart"

Why is the RV the Achilles heel?

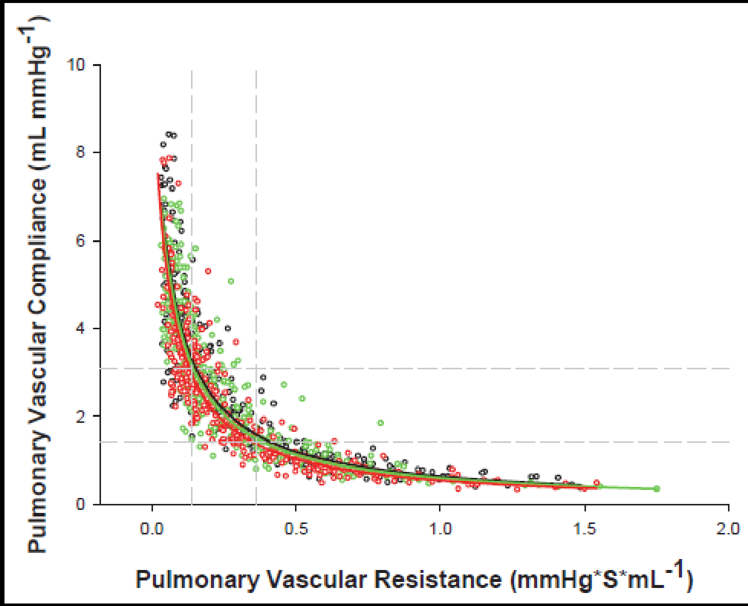
	Left Ventricle	Right Ventricle
Cardiac Output (L/min)	5	5
Vascular resistance (dyne-sec.cm^5)	1100	70
Afterload Pressure (mmHg)	130/ 75 (85)	25/ 9 (15)
Exercise		
Cardiac Output (L/min)	25	25
Vascular resistance (dyne-sec.cm^5)	↓↓↓	↓
Afterload Pressure (mmHg)	↑	↑↑↑

It’s all about hoses

In a pulsatile circulation we need to consider compliance

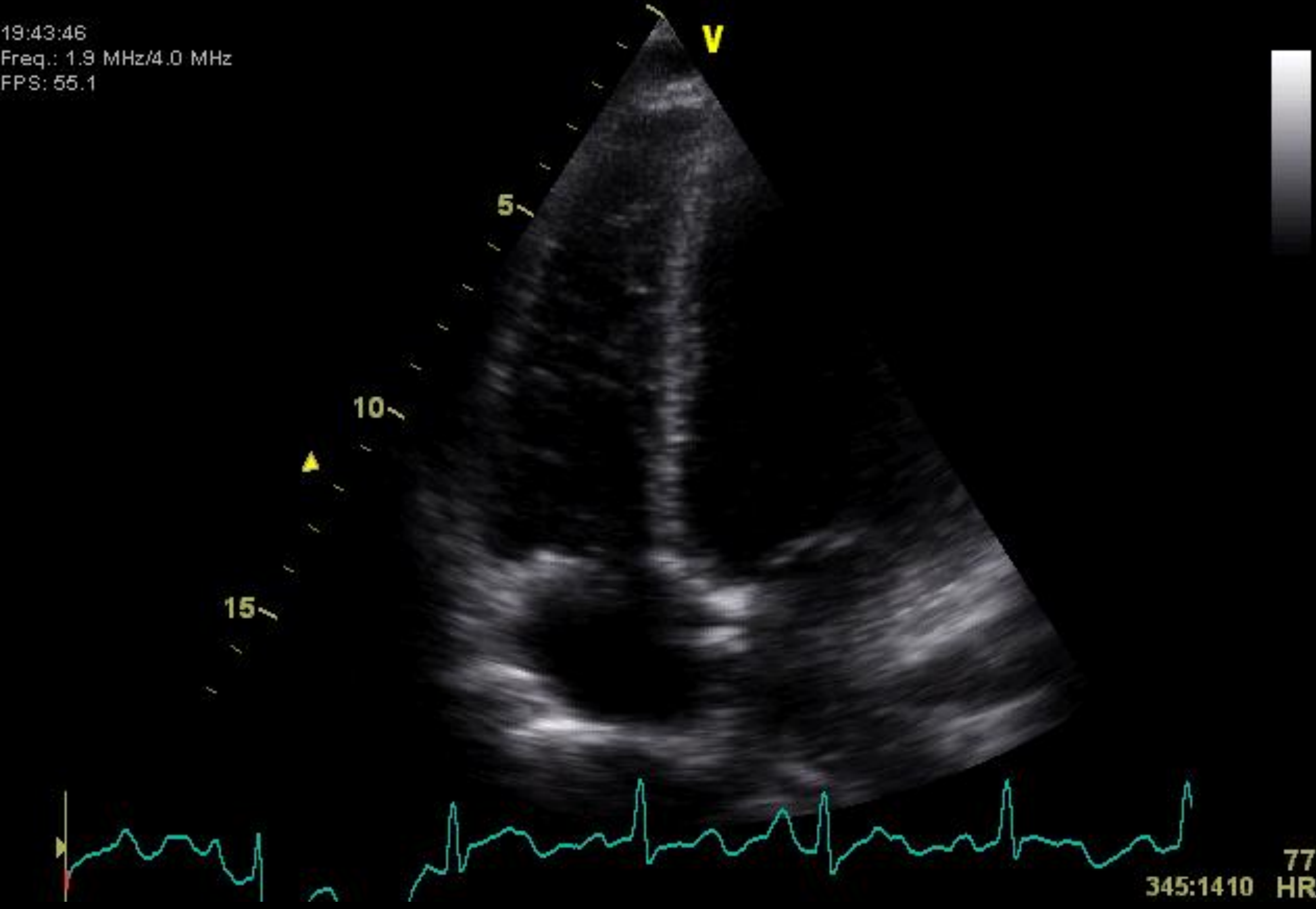


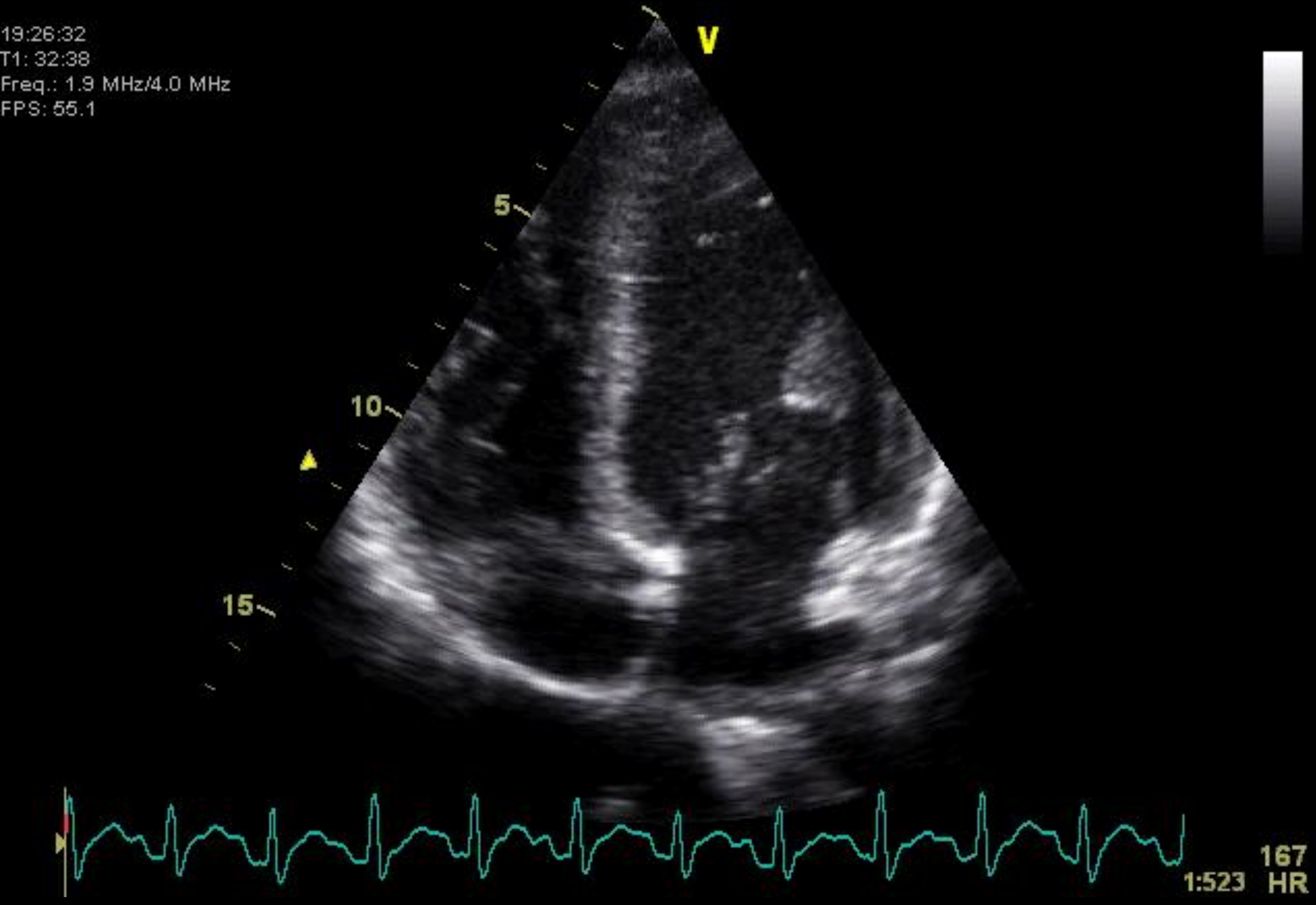
Lankhaar et al. *EHJ 2008*

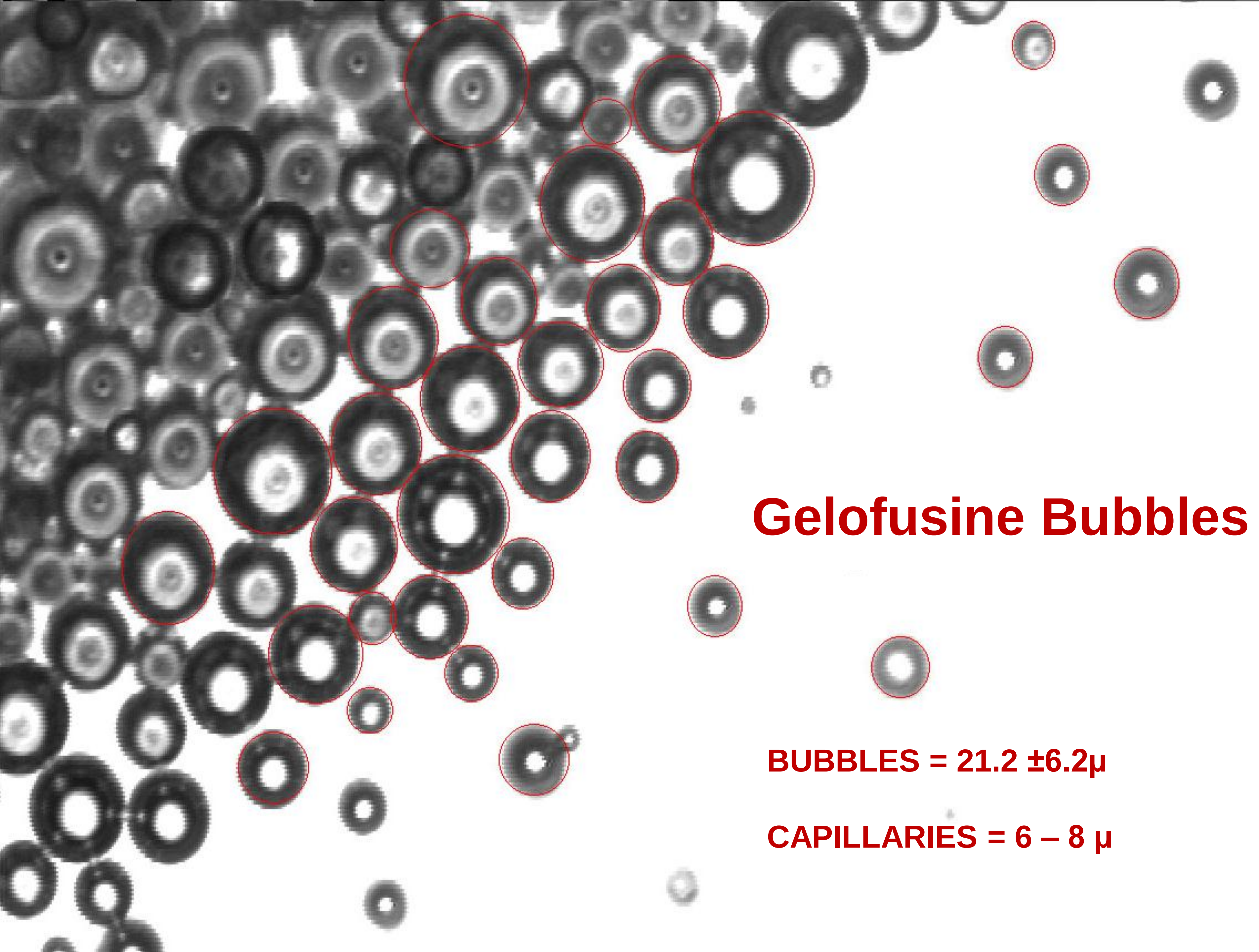


Tedford, Kass et al. *Circ* 2011

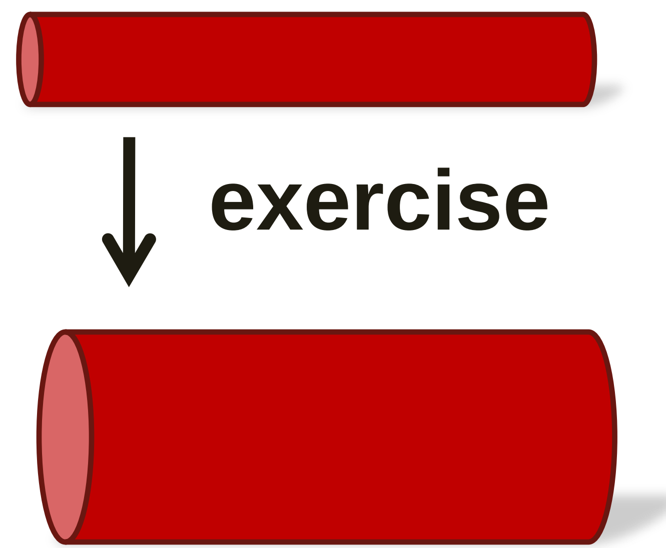
- To maximise *pulsatile* flow you want big vessels that can distend
- Flow $\propto$ P x r^4 /η x L


19:43:46
Freq.: 1.9 MHz/4.0 MHz
FPS: 55.1
V
5
10
15
77
345:1410
HR


19:26:32
T1: 32:38
Freq.: 1.9 MHz/4.0 MHz
FPS: 55.1
V
5
10
15
167
1:523
HR


Gelofusine Bubbles
BUBBLES = 21.2 ±6.2μ
CAPILLARIES = 6 – 8 μ

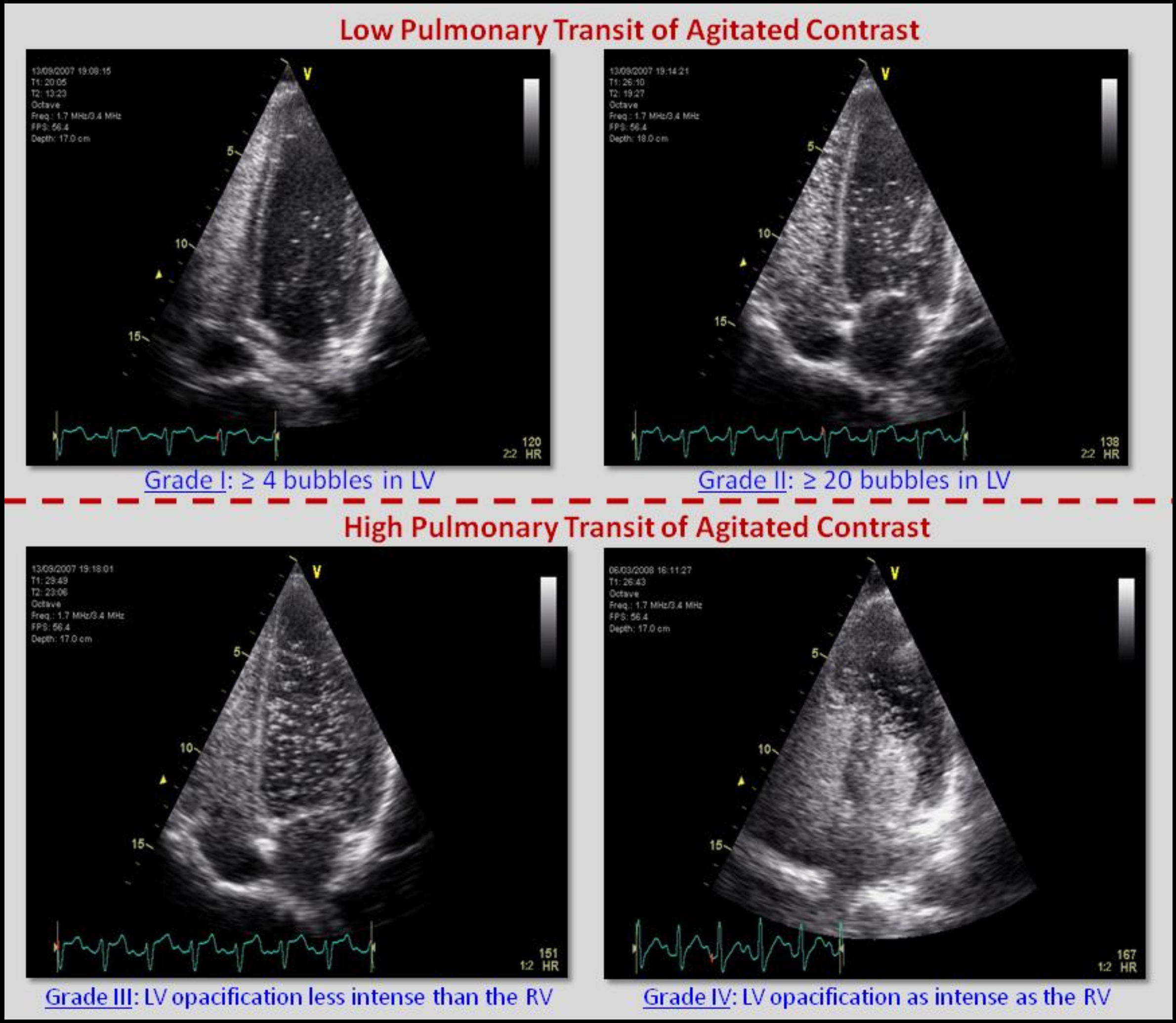
? indicates larger vessels



…..and larger calibre vessels result in
lower pressures and resistance
and higher flows

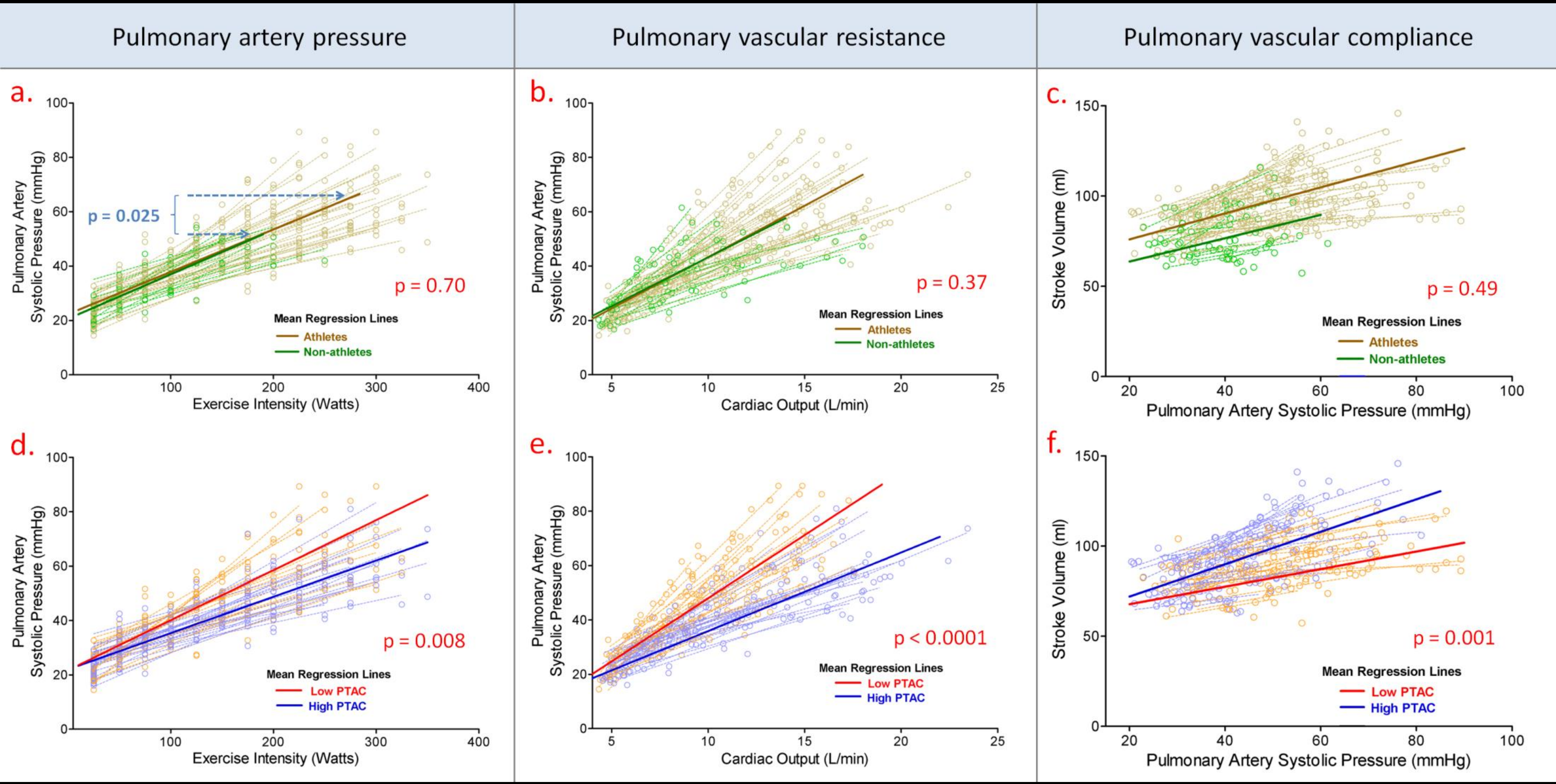
Pulmonary transit of contrast (PTAC)

- 40 athletes and 15 non-athletes
- Graded PTAC
- Equal proportion of PTAC



La Gerche, Voigt, Heidbuchel, Prior et al. *J App Physiol* 2010

Lower pulmonary pressures and resistance



La Gerche, Voigt, Heidbuchel, Prior et al. *J App Physiol* 2010

PTAC predicts performance

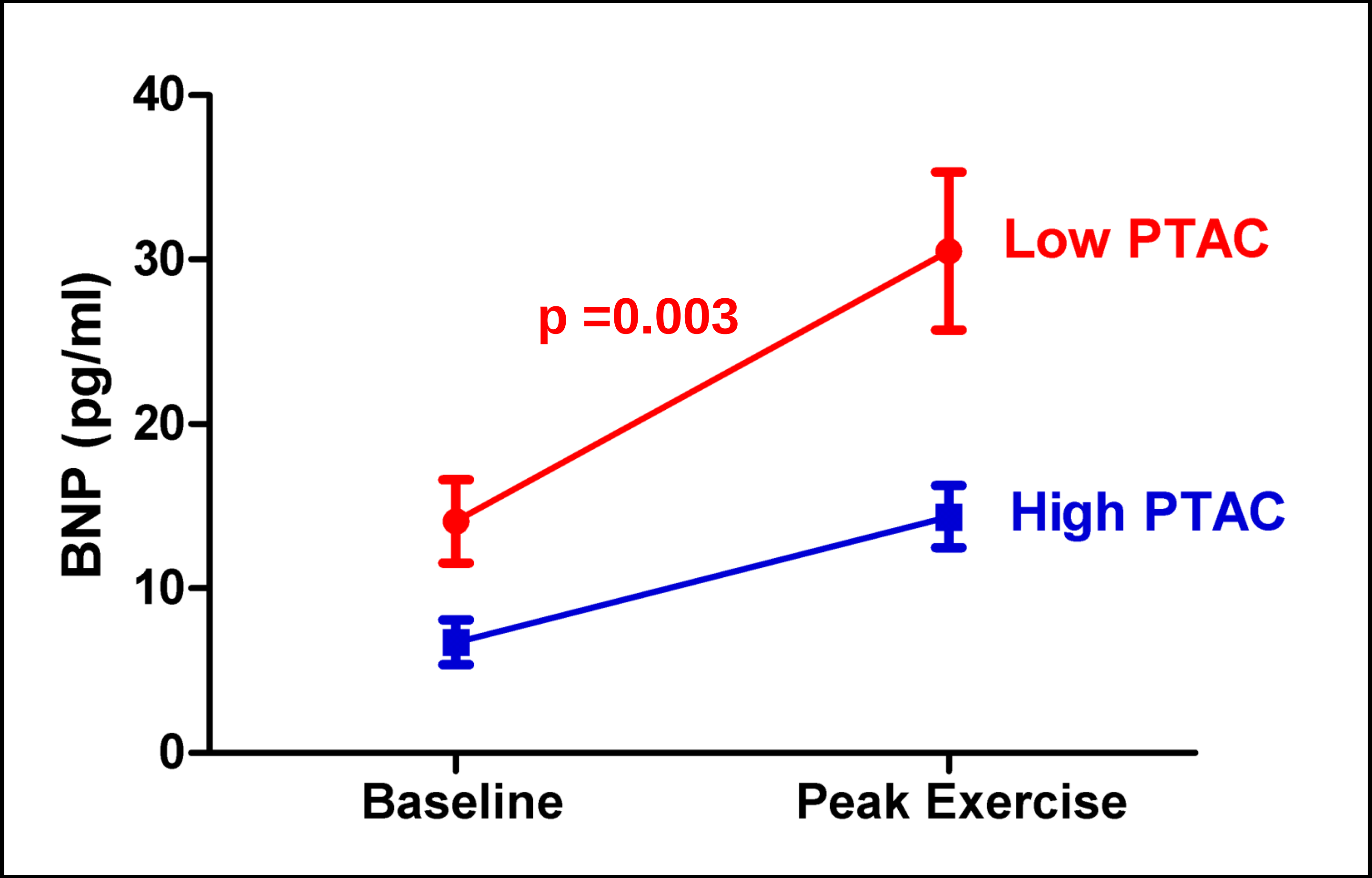
- PTAC was associated with a 16% greater peak exercise CO
- PTAC was an independent predictor of VO_2 max and maximal exercise output

Better RV function associated with PTAC

	Rest		p-value	Peak-Exercise		p-value
	High-PTAC	Low-PTAC	Baseline	High-PTAC	Low-PTAC	Interaction with exercise*
RV Function						
RV Sm (cm/s)	**11.2±2.4**	**11.1±1.4**	**0.72**	**21.5±4.5†**	**18.9±2.9†**	**0.009**
RV Em (cm/s)	**11.3±3.4**	**10.9±2.1**	**0.98**	**33.6±6.7†**	**30.4±6.8†**	**0.010**
RV IVA (cm/s^2)	**1.7±0.7**	**1.7±0.8**	**0.83**	**6.9±2.7†**	**5.1±1.9†**	**0.001**
LV function						
LV Sm (cm/s)	**6.4±1.6**	**6.3±1.2**	**0.64**	**13.5±3.2†**	**12.3±2.5†**	**0.10**
LV Em (cm/s)	**9.0±1.8**	**8.7±1.9**	**0.63**	**19.6±3.7†**	**17.6±4.0†**	**0.21**
LV IVA (cm/s^2)	**1.4±1.4**	**1.3±1.0**	**0.75**	**3.4±1.1†**	**2.9±1.5†**	**0.35**

La Gerche, Voigt, Heidbuchel, Prior et al. *J App Physiol* 2010

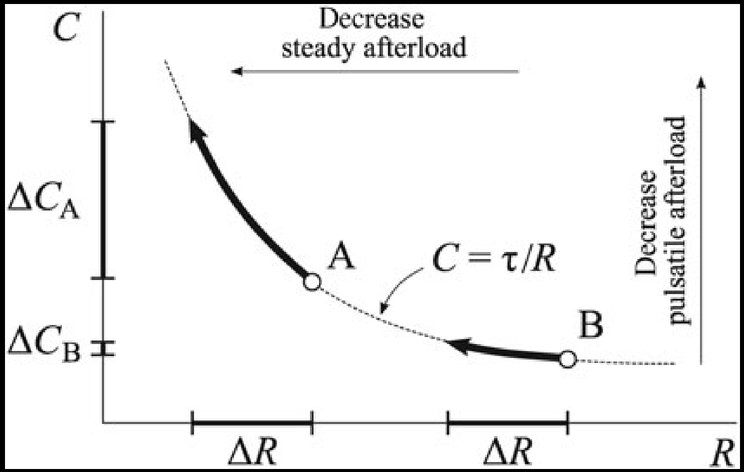
Attenuated BNP increase in high PTAC



La Gerche et al. *J App Physiol* 2010

Trans-pulmonary bubbles

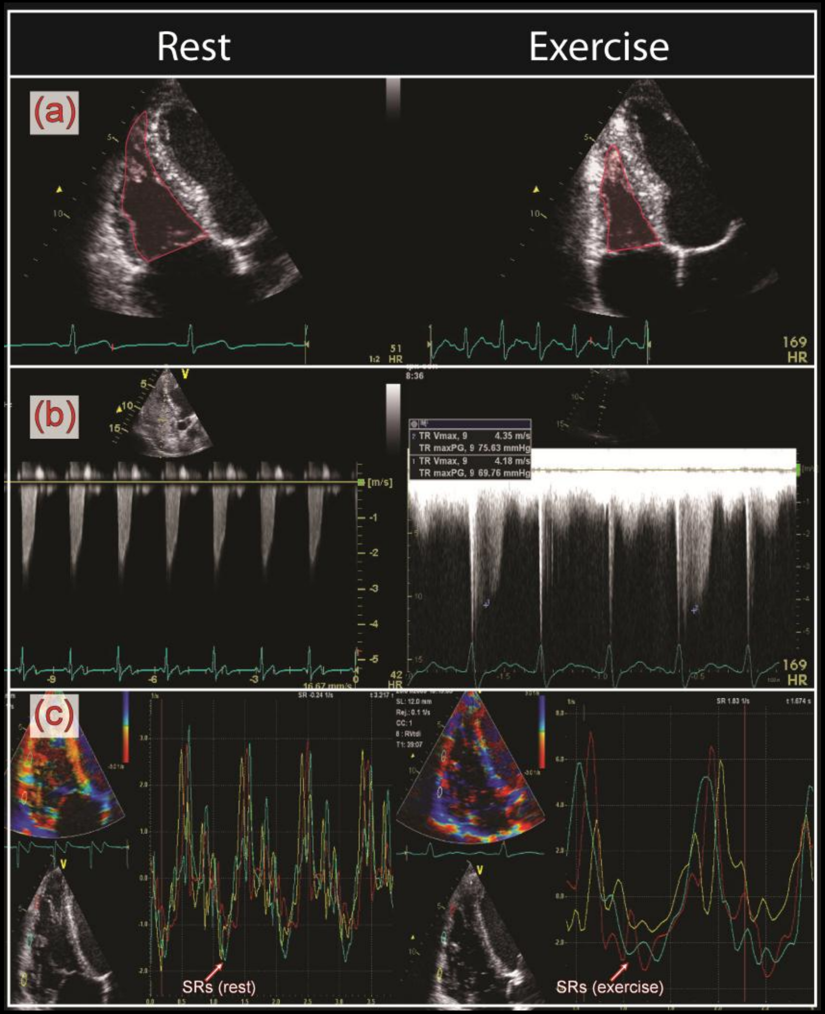
- Are associated with enhanced pulmonary vessel hemodynamics, RV function and exercise capacity
- May be a surrogate measure of pulmonary vessel size and compliance
- ??? Early marker of pulmonary vessel pathology



Lankhaar et al. *EHJ 2008*

So, RV function during exercise may be important but how can I measure it?

RV Stress test



RV areas

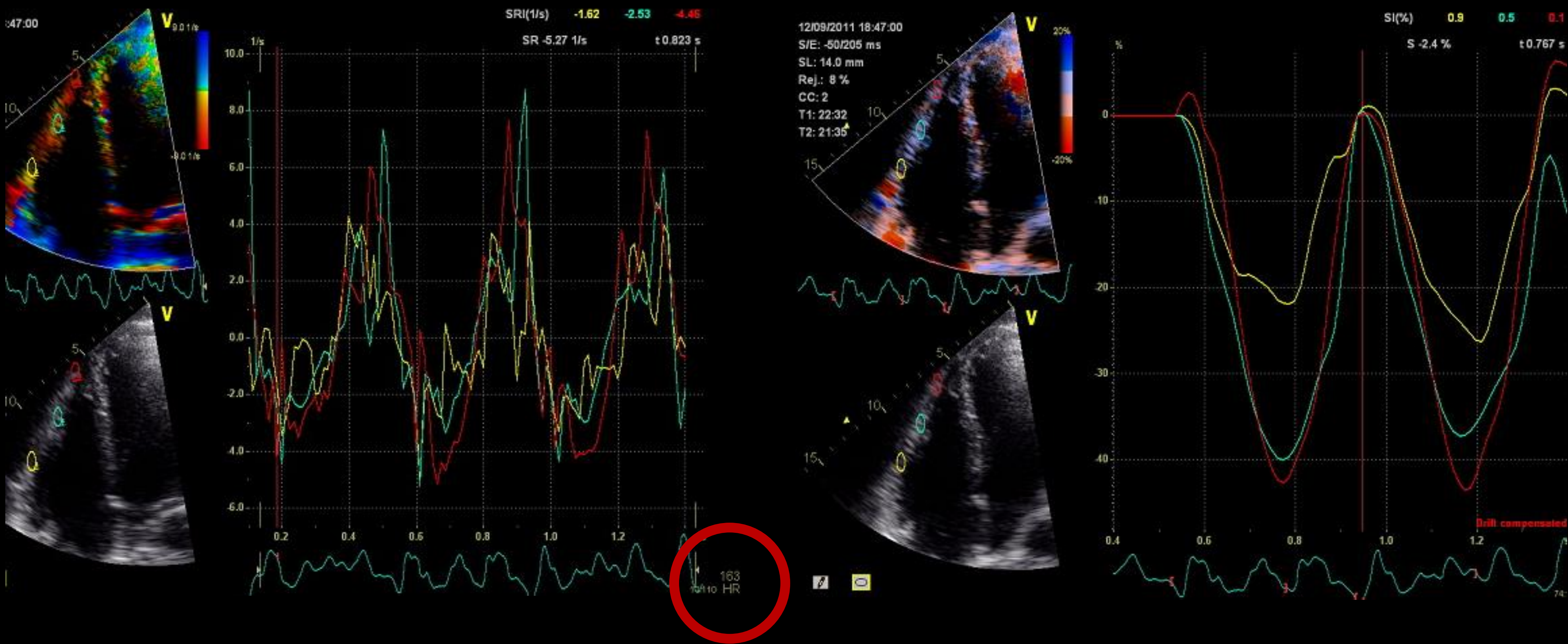
PASP estimates

Pressure/area relationship

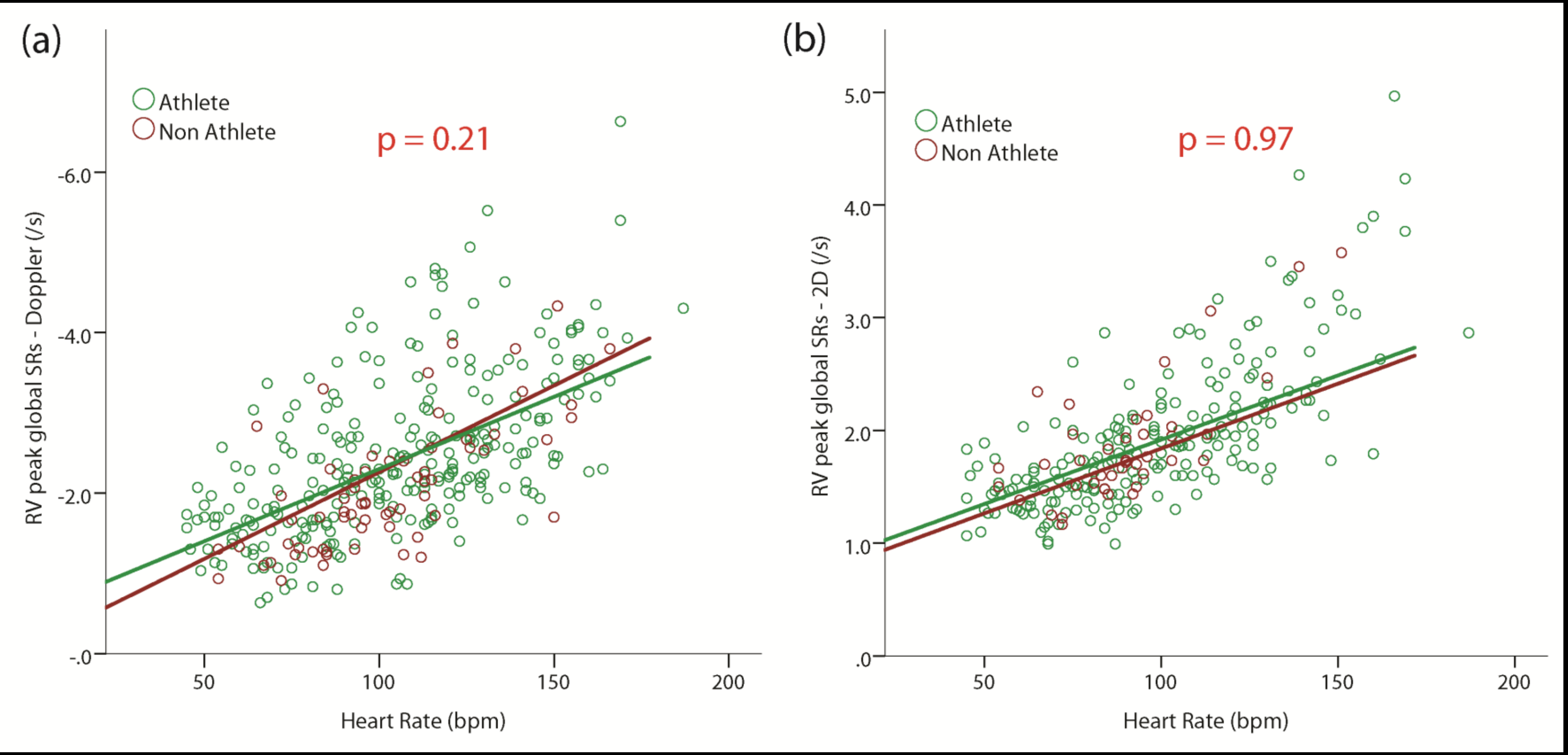
RV velocities, strain/ rate

La Gerche, D'Hooge, Heidbuchel, Prior et al. *JASE* 2012

Deformation during exercise

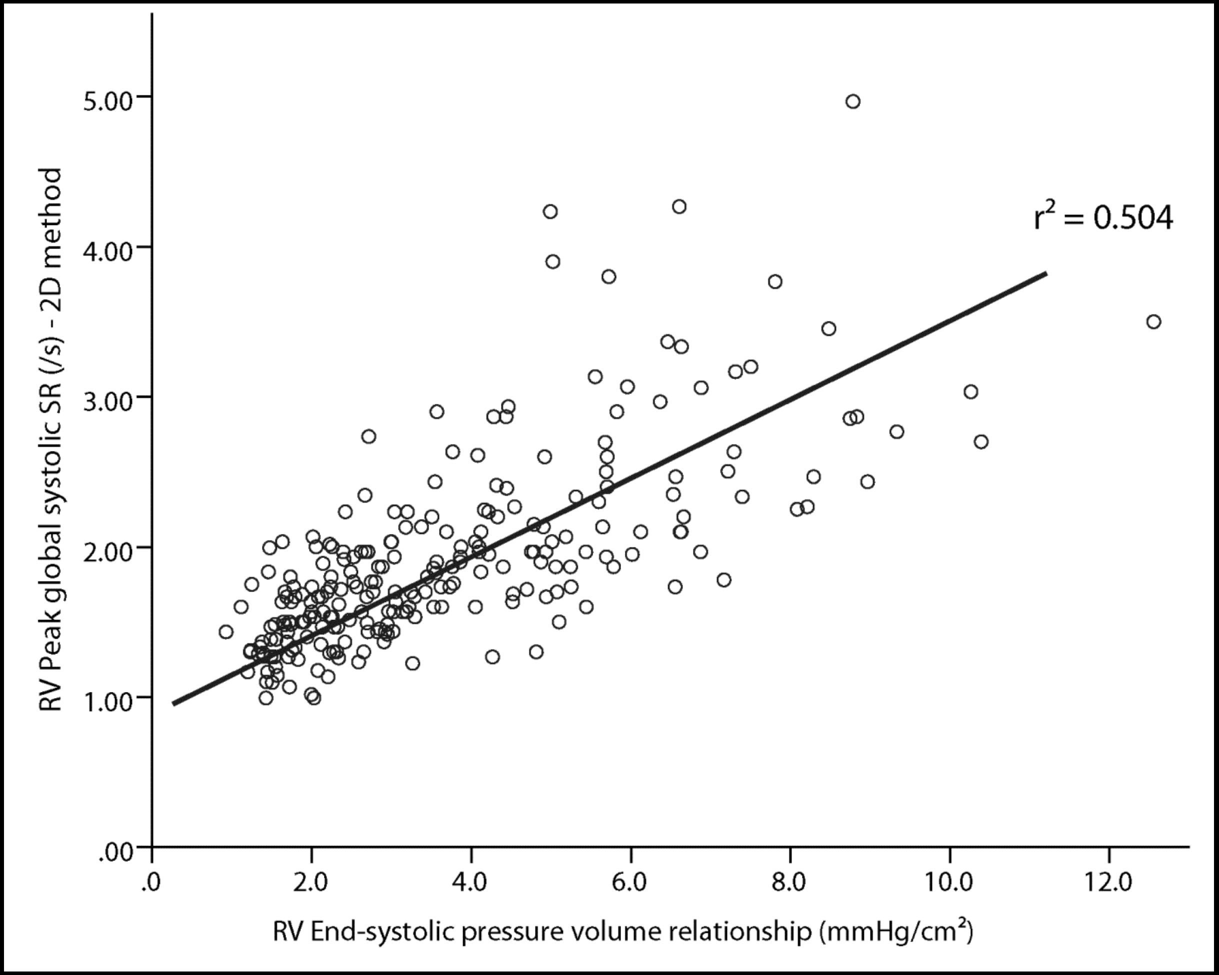


RV strain rate increases with exercise



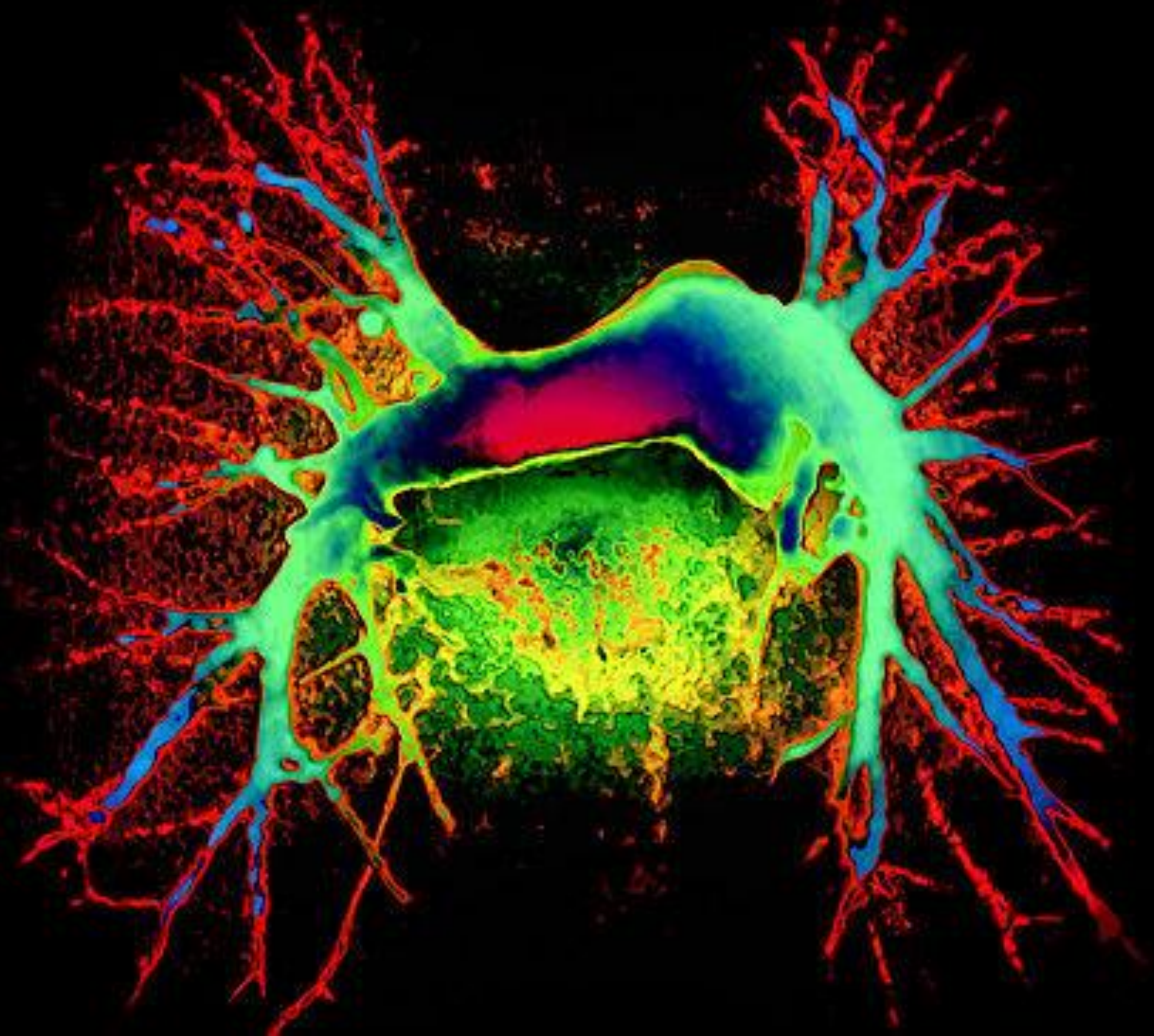
La Gerche, D'Hooge, Heidbuchel, Prior et al. *JASE* 2012

Two non-invasive surrogates singing the same tune?

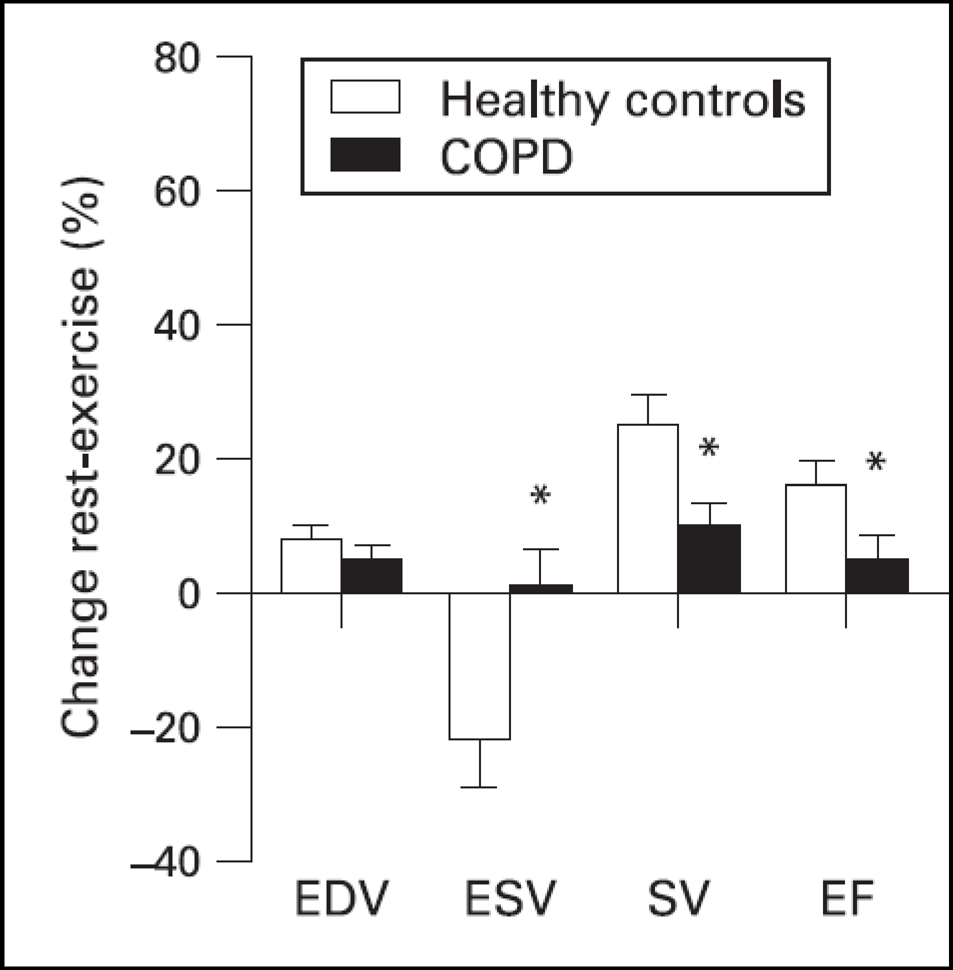


La Gerche, D'Hooge, Heidbuchel, Prior et al. *JASE* 2012

Translational exercise science
- from normal to pathology

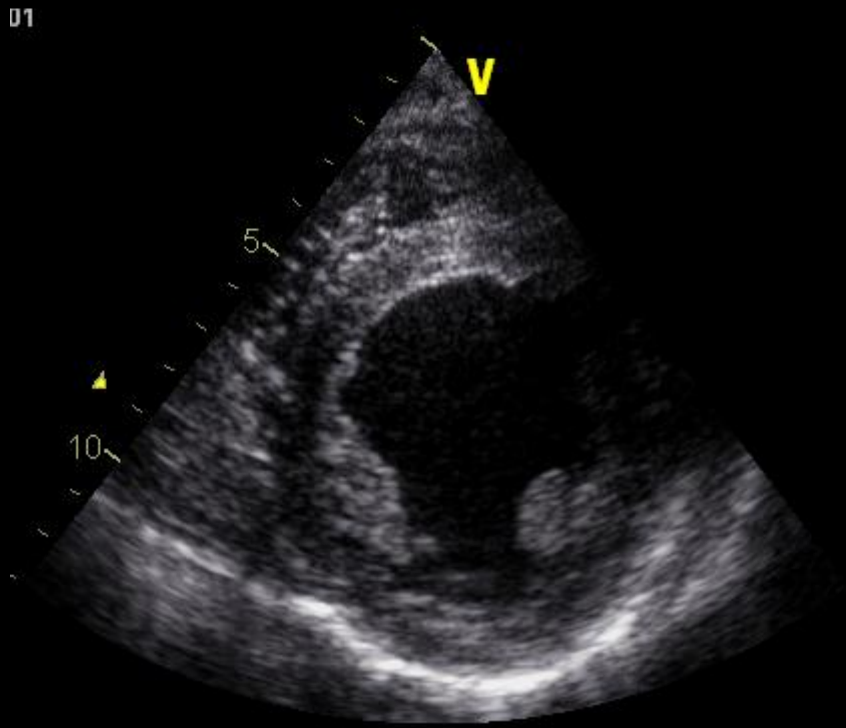


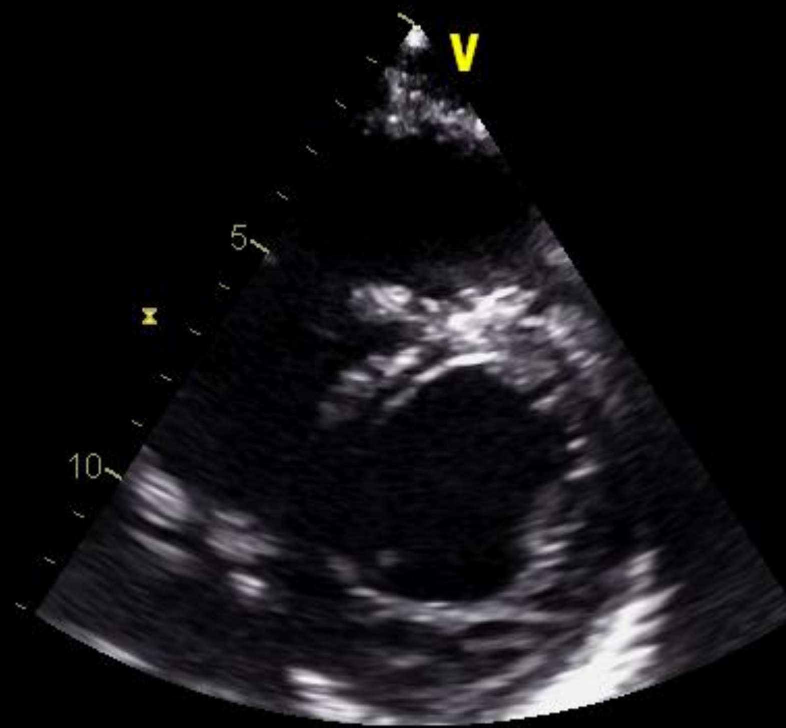
Failure of RV function limits exercise cardiac output in PHTn



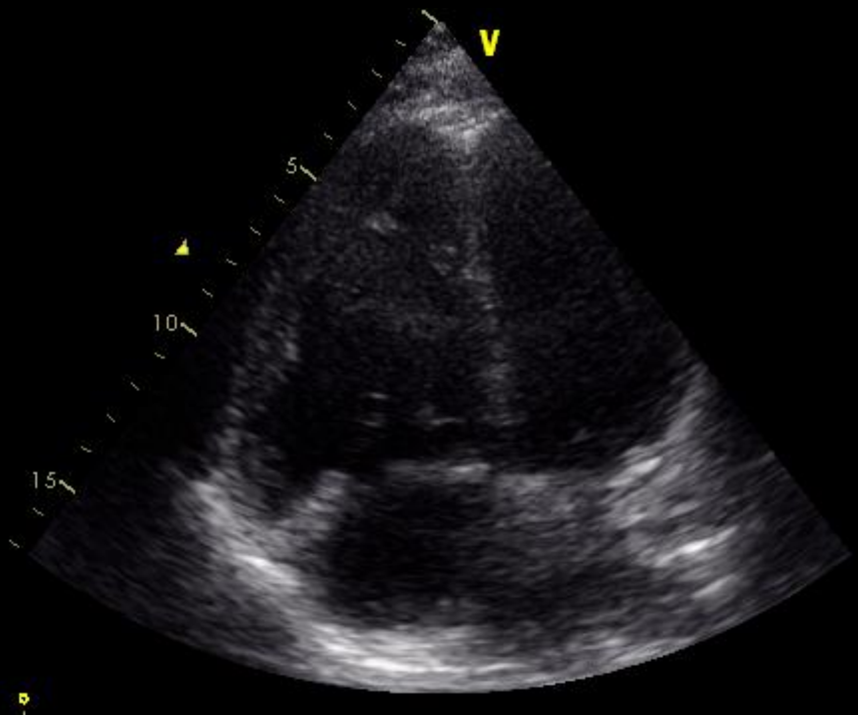
Holverda, Vonk Noordegraaf et al. *Heart* 2009

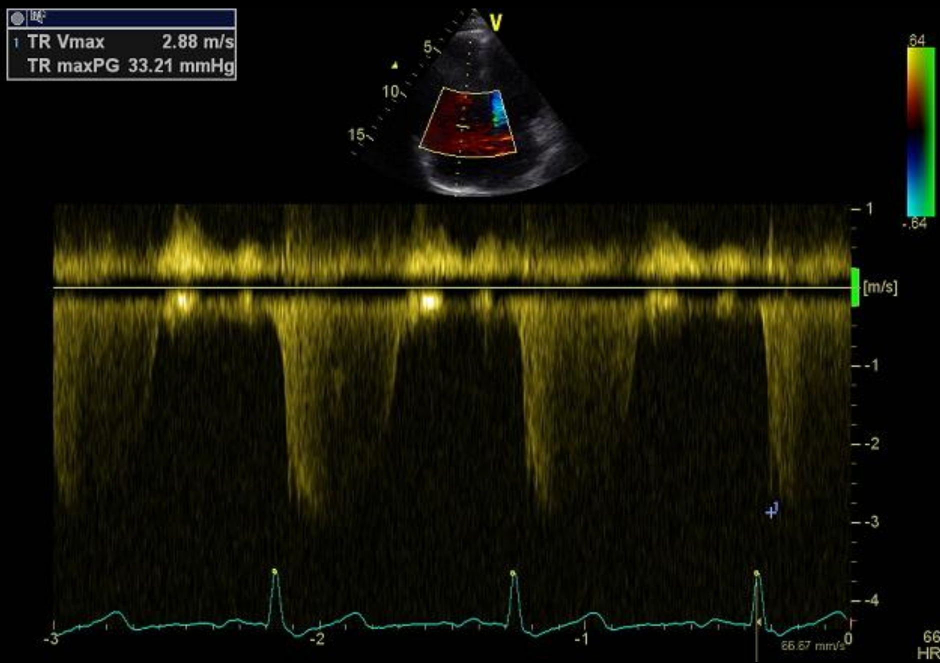
Elite cyclist with ? subtle ARVC



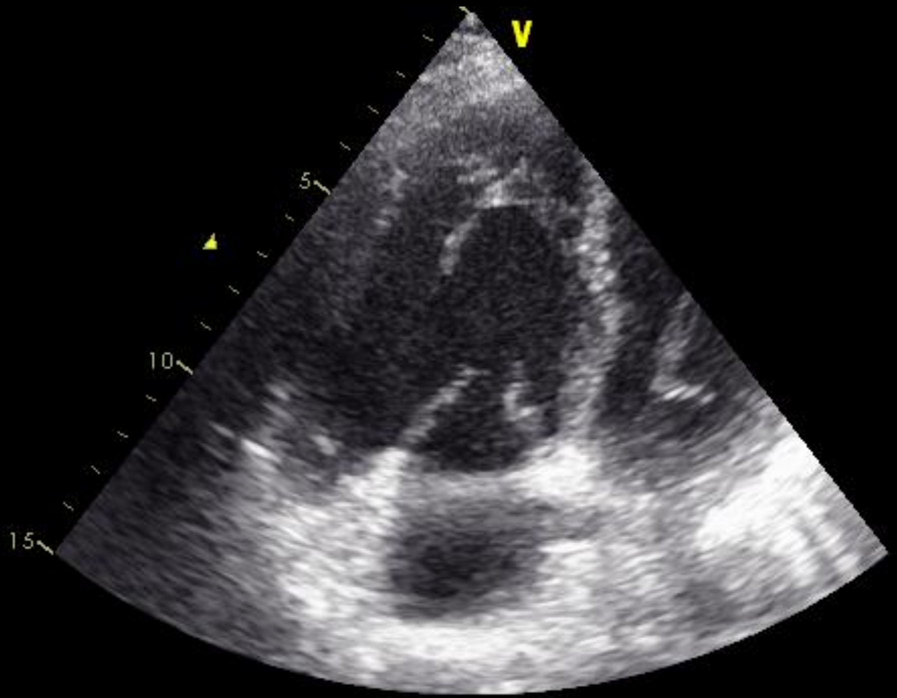


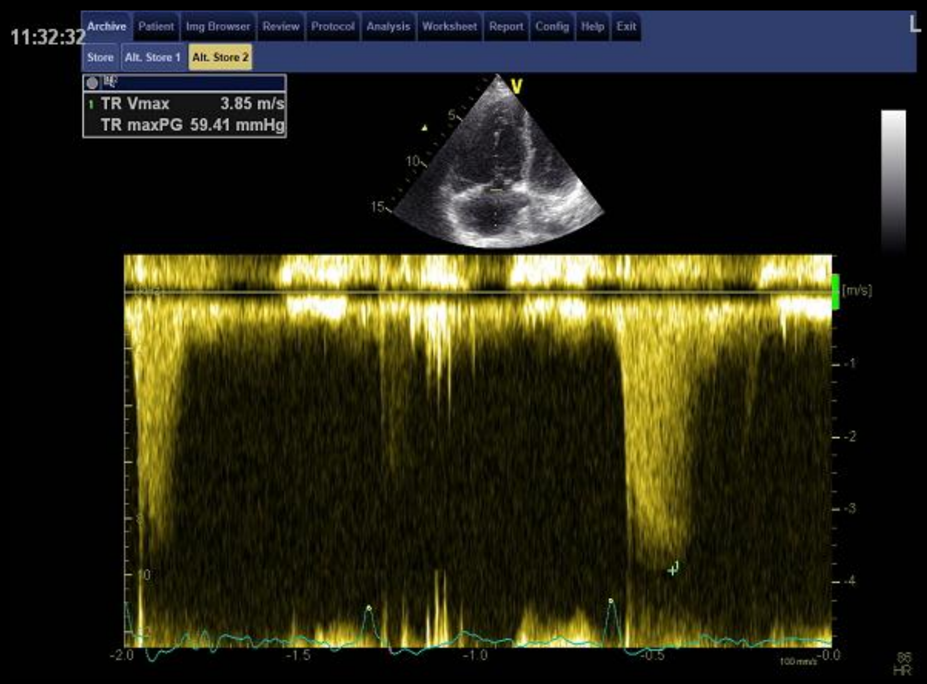
28 yo lady with recently diagnosed ASD



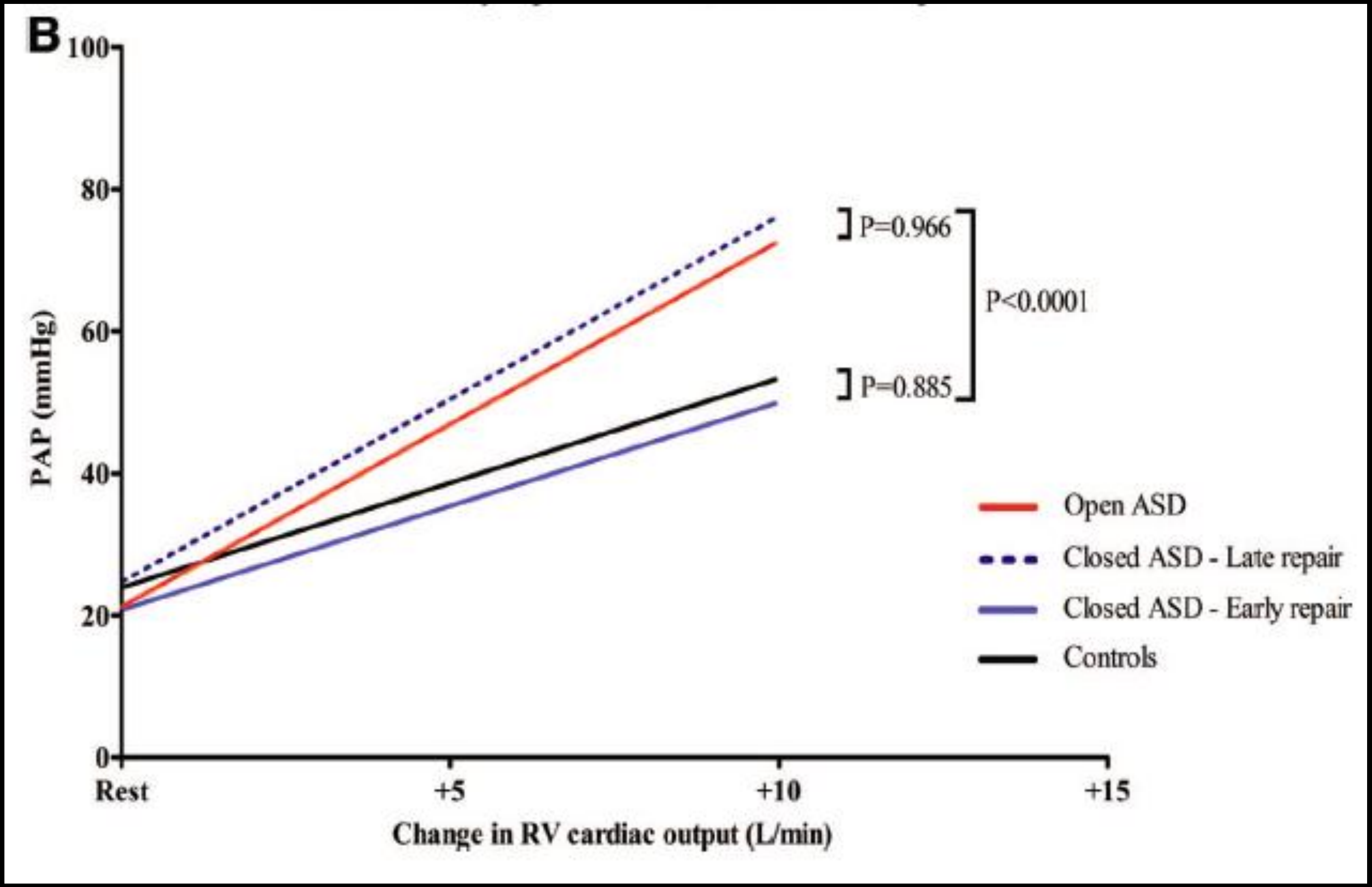


ASD exercise





Increased pulmonary vascular resistance in unrepaired ASD's



Van DeBruaene et al. *Circ CVS Imag* 2011

Conclusions

- Recognise the limitations of assessing the RV at rest
- Exercise places an important (and possibly disproportionate) load on the RV
- RV/ pulmonary vascular function can limit exercise performance – in disease and health
- ‘RV reserve’ *may* be useful in predicting functional decline and prognosis

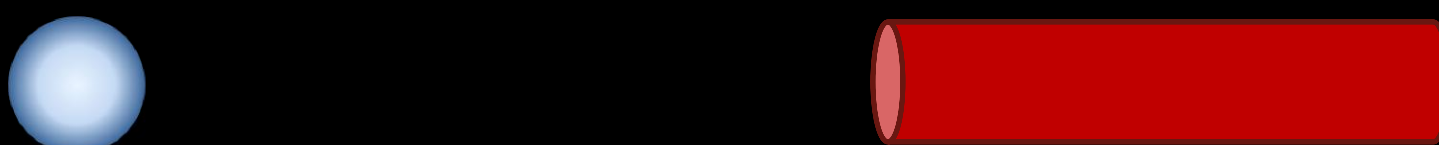
Thank you

How can big bubbles get through a little tube?

Bubbles break up

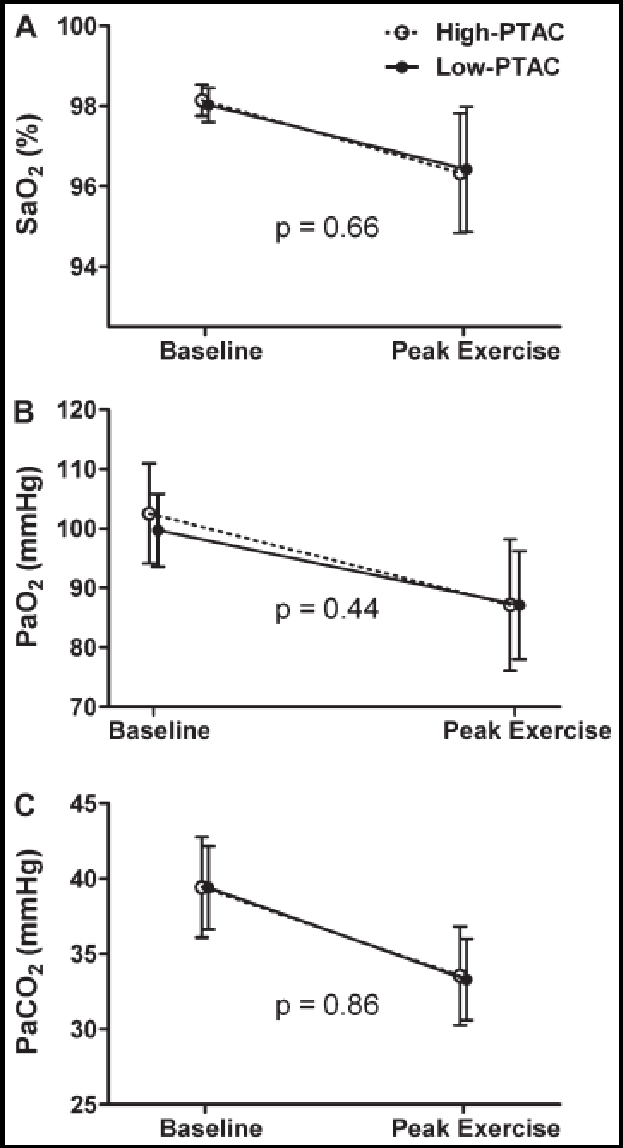
AV shunts open

Pulmonary vessels distend



AV Shunts ??

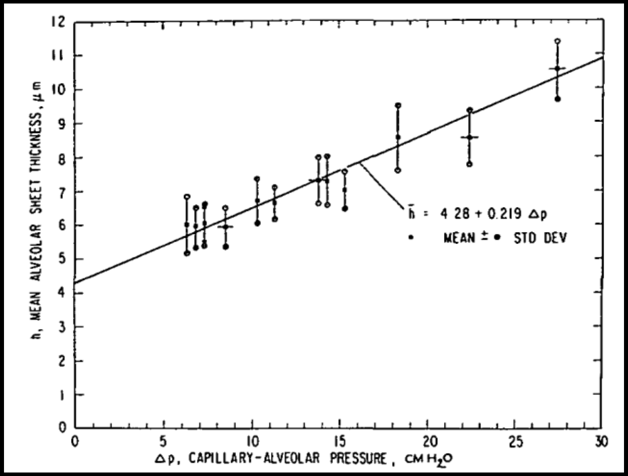
- SaO_2 and PaO_2 decreased in athletes but there was ***no*** relationship between exercise induced hypoxemia and PTAC
- PTAC is unlikely to represent shunting (alone)



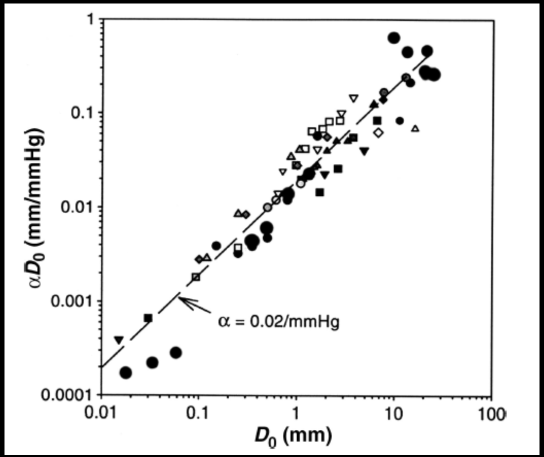
Distensibility ??

- Pulmonary capillary distensibility has been demonstrated in rapid freeze animal models (Sobin 1972, Glazier 1969)
- Reeves compared a theoretical schema with human data and determined that:

  pulmonary vessels distend 2% for every 1mmHg increase in mPASP



Sobin et al. *Circ Res* 1972



Reeves et al. *Am J Physiol Lung Cell Mol Physiol 2005*

Increased afterload

- Pulmonary hypertension, pulmonary arterial hypertension etc.
- Need to consider both deformation and load