Απεικόνιση στην Πνευμονική υπέρταση. Από το screening στην αξιολόγηση κινδύνου και παρακολούθηση θεραπείας. Καρδιαγγειακή μαγνητική τομογραφία (CMR)

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Nothing to disclose

Right Heart Changes in Pulmonary Hypertension

- RV hypertrophy involving the papillary muscles, trabeculations and IVS
- Asymmetric septal hypertrophy may be present
- Progressive RV dilatation
- Abnormal IVS motion
- Tricuspid regurgitation as a consequence of RV dilatation
- Interatrial septum is convex leftwards reflecting elevated RA pressures
- Dilated RA
- Plethoric vena cavae
- Pericardial effusion

Why CMR in PAH???

Implications of cardiac variability with CMR for calculating trial sample size in PAH

- **Low cardiac variability** was measured with CMR in PAH.
- This enables the **statistically strong detection** of clinically relevant changes with a small trial sample size.

Göransson C et al. Int J Cardiol. 2018

CMR can assess prognosis-treatment

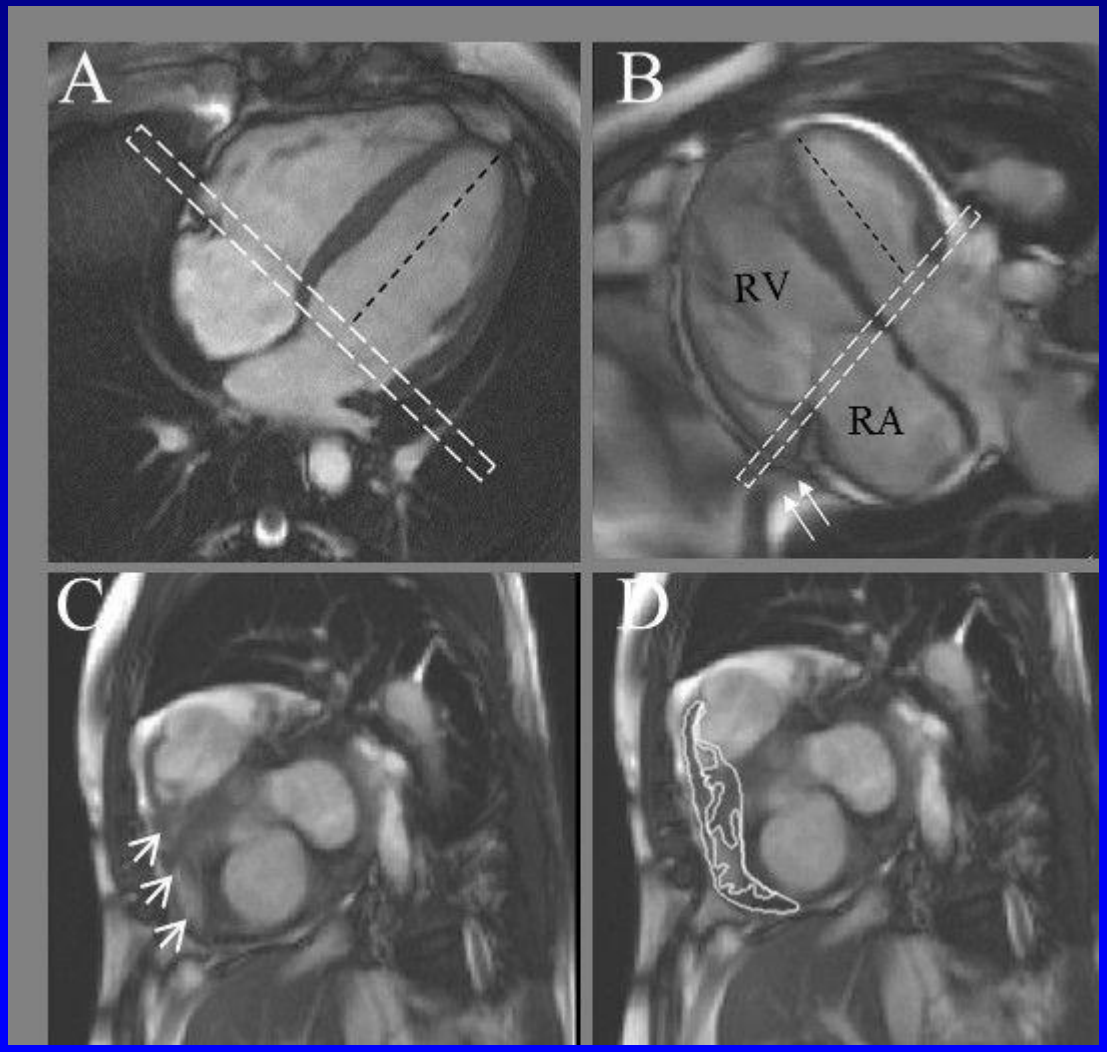
- Well suited to longitudinal follow up
- Evaluation of RV structure, function, mass
- Main PA distensibility
- Fewer patients needed due to its high interstudy repeatability
- Baseline RVEDV, SV and LVEDV and RVEF
- PA stiffness

Suggested CMR Protocol in PH

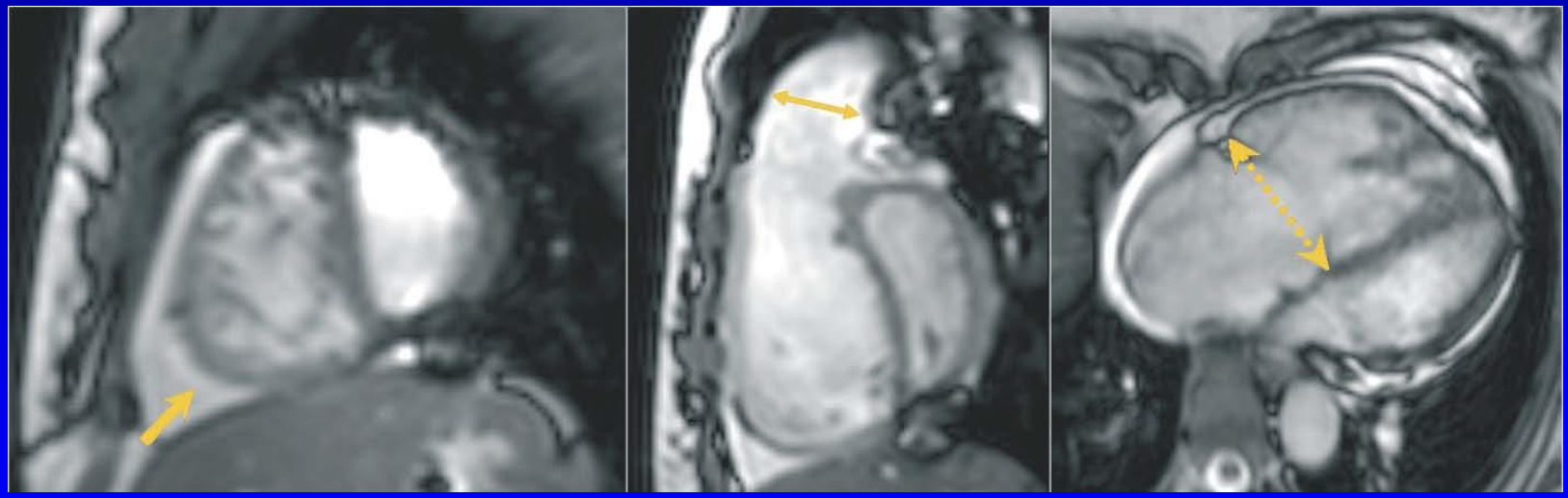
- Localisers to identify the position of the heart (Sagittal, coronal, axial)
- Cines to define axes of both ventricles and the great arteries
- Flow Measurements to determine stroke volume through main pulmonary artery and aorta
- Magnetic Resonance Angiography to assess the pulmonary arterial tree
- Late Gadolinium Enhancement (LGE) to exclude areas of infarction and determine the degree of insertion region enhancement

Biventricular evaluation

Acquisition of Volumetric Data



Gradient-echo cine images acquired using SSFP from patients with severe pulmonary arterial hypertension.



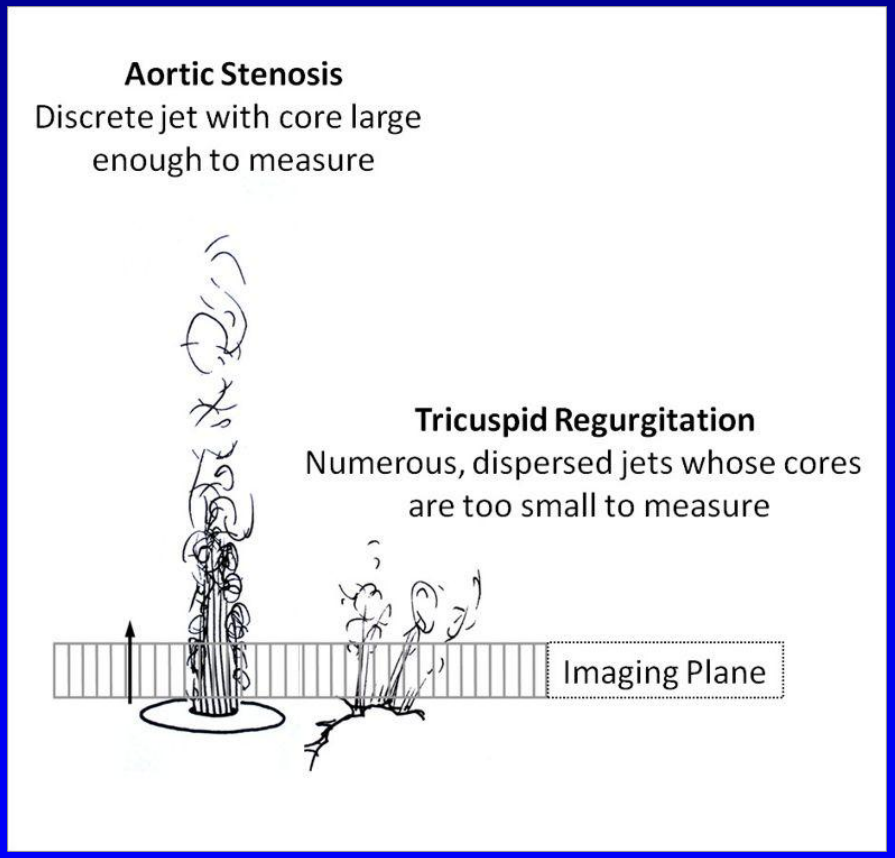
Analysis of Right Ventricular Indices

- No consensus as to how to do RV analysis
- RV mass includes the papillary muscles and trabeculae and 'RV' septum, if it is hypertrophied
- Determine biventricular volumes in the frame with the most abnormal septal position, and the four preceding it, before choosing the smallest volume as end-systole for each ventricle.
- Alternatively, end-systole can be defined using valve opening and closure

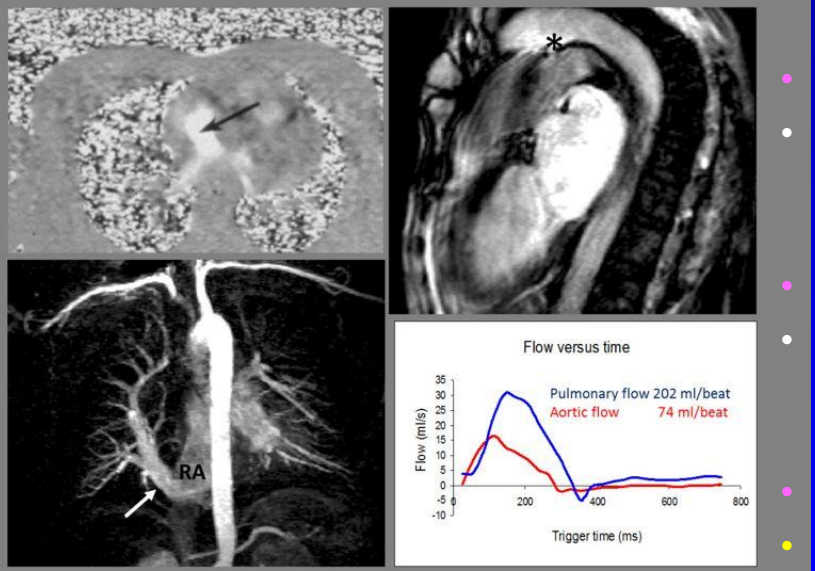
PA anatomy and function

Noninvasive hemodynamics

- Lack of a single, robust non-invasive INDEX
- RV mass
- Degree of septal displacement
- Pulmonary pressures is inversely correlated with blood velocity in main PA
- PWV: velocity-encoded data and cross-sectional area change of the main PA
- Measuring Transit-Time PWV in the Pulmonary Arteries.



CMR in Group 1 PAH due to Congenital Heart Disease



- **Top left,**
- In plane flow mapping demonstrating flow between left and right atrium (arrow) through an **atrial septal defect**;

- **Top right,**
- SSFP showing flow (asterisk) from descending aorta to PA via a **persistent ductus arteriosus;**

- **Bottom left,**
- MRA of an **aberrant pulmonary vein** (arrow) draining into right atrium (RA)

- **Bottom right,**
- **flow mapping** in this patient in the main pulmonary artery and aorta allowed a Qp:Qs of 2.7

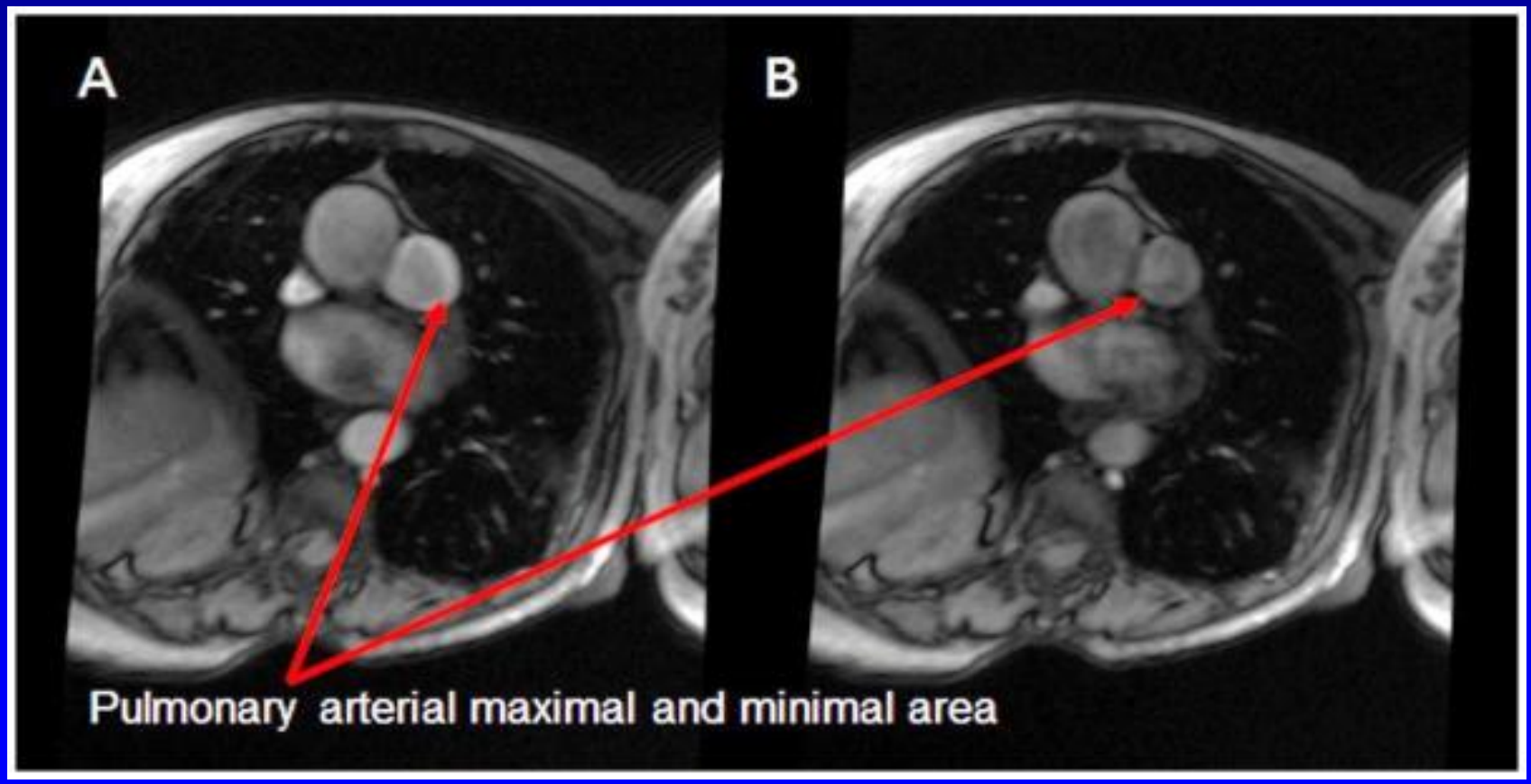
Journal of Cardiovascular Magnetic Resonance 2012

Pulmonary arterial stiffness assessed by CMR is a predictor of mild PAH

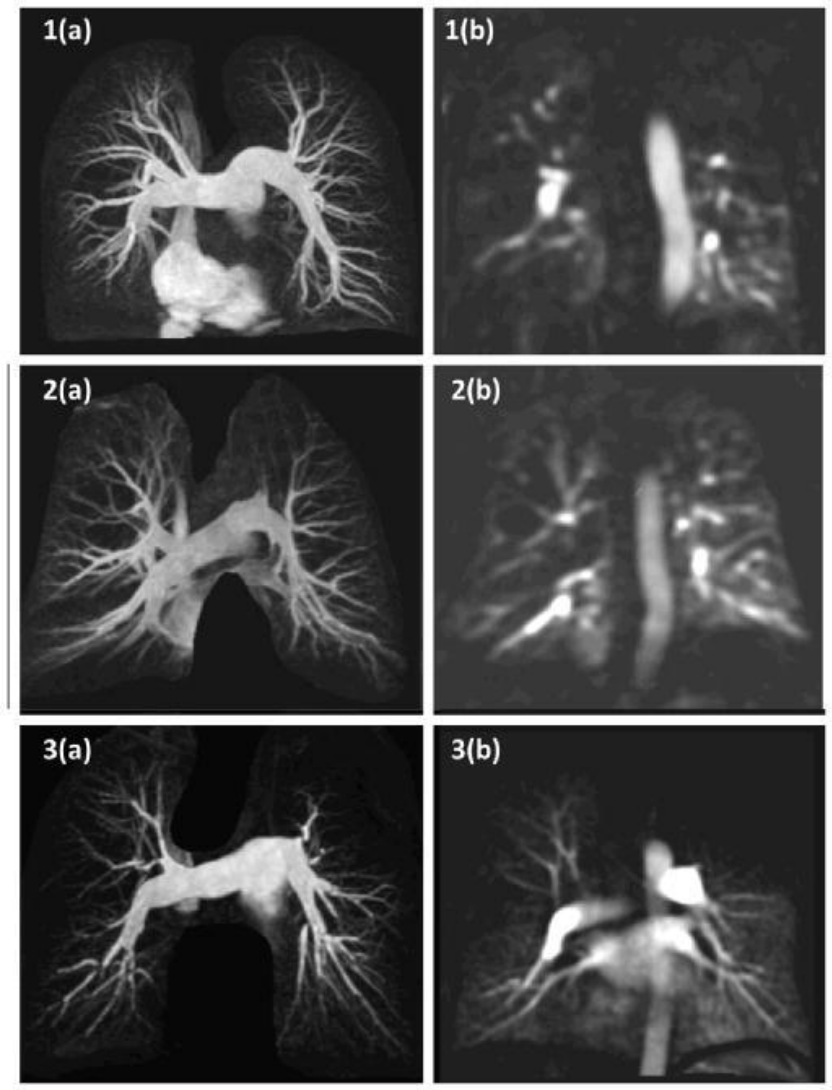
- **PA pulsatility <40%** is excellent to discriminate between mild PAH and normal controls.
- This approach has a **sensitivity of 95% and specificity of 94%.**

Ray JC Int J Cardiovasc Imag 2018

Pulmonary artery images for calculation of relative area change

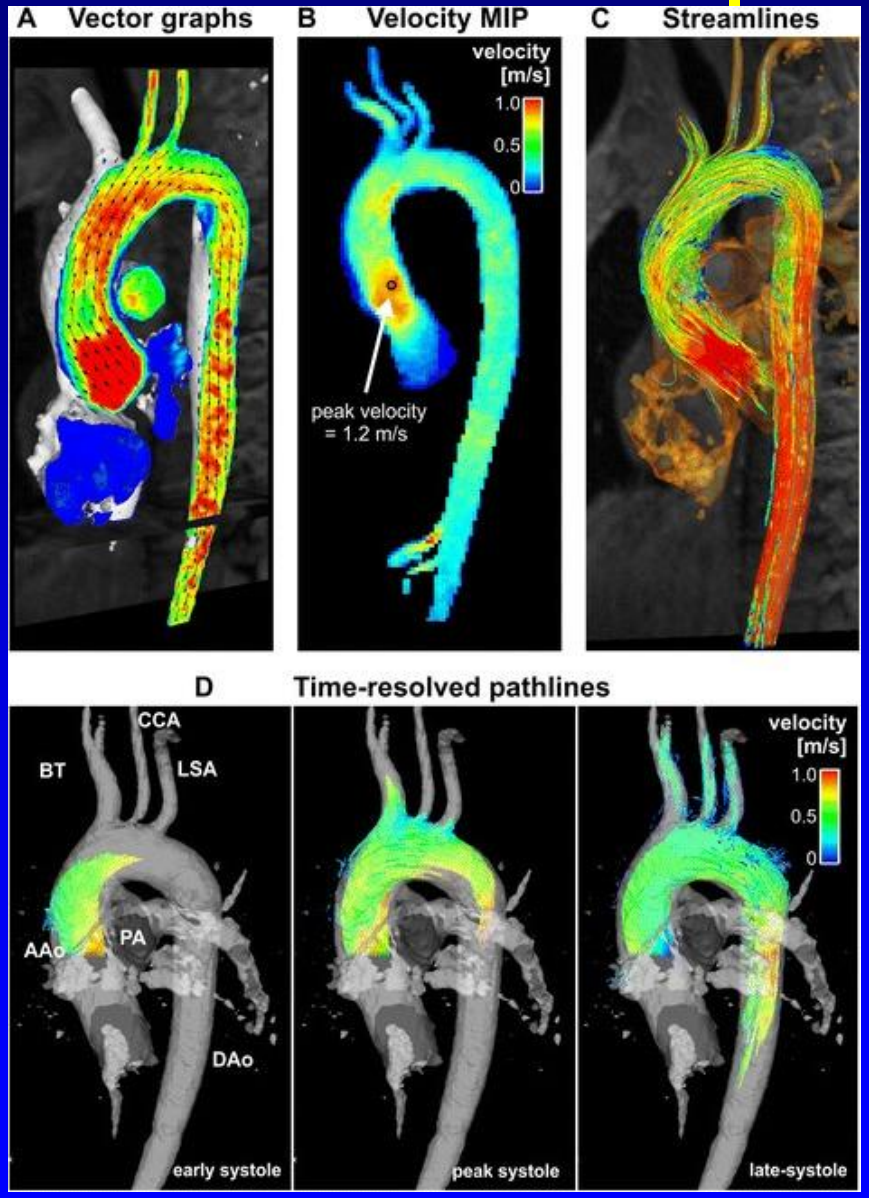


MRA and perfusion images in PH



- 1(a/b) IPAH with vessel tortuosity and patchy perfusion
- 2 (a/b) COPD/emphysema and associated reduced perfusion in the upper zones
- 3 (a/b) CTEPH and associated segmental perfusion defects

4D flow CMR



- **4D Flow CMR:**
- **Pro**
-
- **offers the ability to retrospectively calculate blood flow through any planes of interest**
- **measures velocity in all spatial directions**
- **has superior spatial coverage and is better at capturing the peak velocity of a stenotic jet**
- **allows for the visualization of multi-directional flow features/alterations of these associated with cardiovascular disease**
- **CONTRA**
- **Long scan time**
- **Post-processing**

PAH vs Controls

- In comparison to controls, PAH patients showed significantly reduced:
- Pulmonary velocities ($p < 0.002$)
- Pulmonary blood flow ($p < 0.002$)
- Pulmonary distensibility ($p < 0.008$) and time-to-peak velocity ($p < 0.001$) with a steeper velocity rise gradient ($p < 0.002$).
- A number of authors have observed highly heterogeneous cross-sectional area flow profiles and retrograde flow in the main PA of PAH patients
- Decreased values of main PA relative area change indicate increased PA stiffness and have been associated with increased mortality

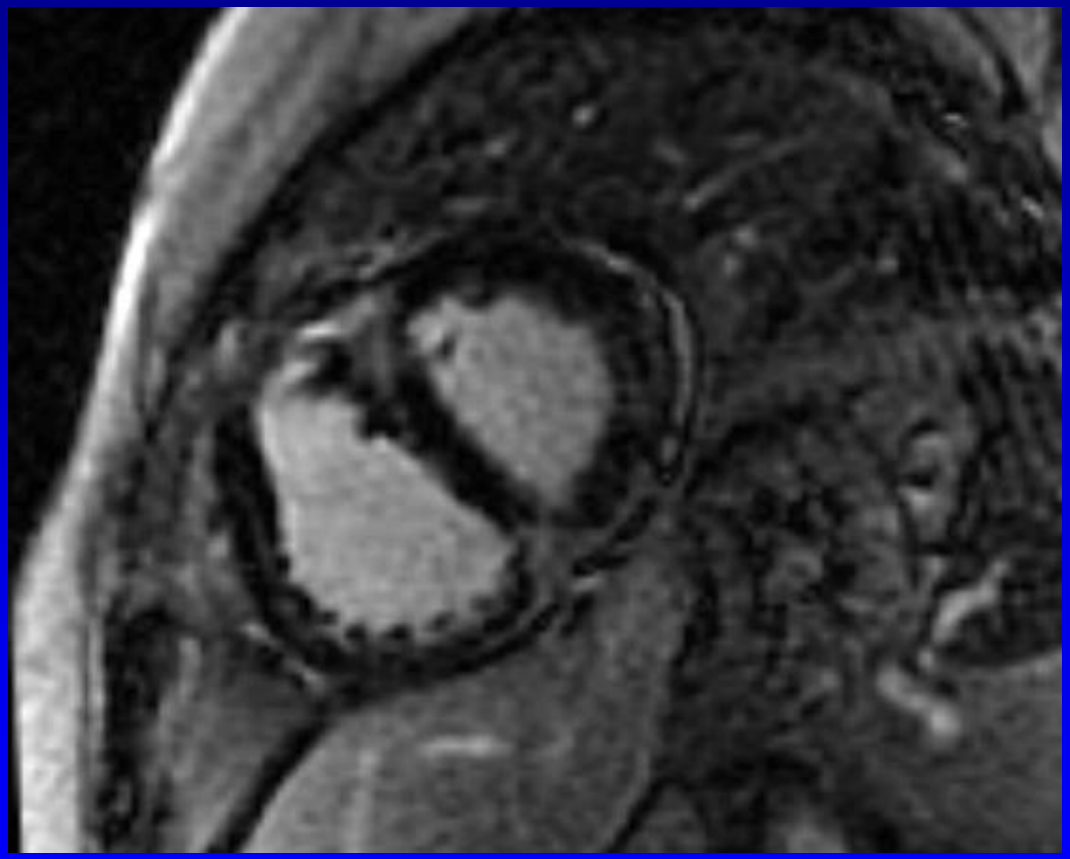
Freed BH et al. JACC CVI 2012

Fibrosis assessment

Late Gadolinium Enhancement

- **LGE limited to the insertion regions**

(myocardial disarray and plexiform fibrosis)



Native T1 image of the same patient showing increased native T1 at the right ventricle insertion points

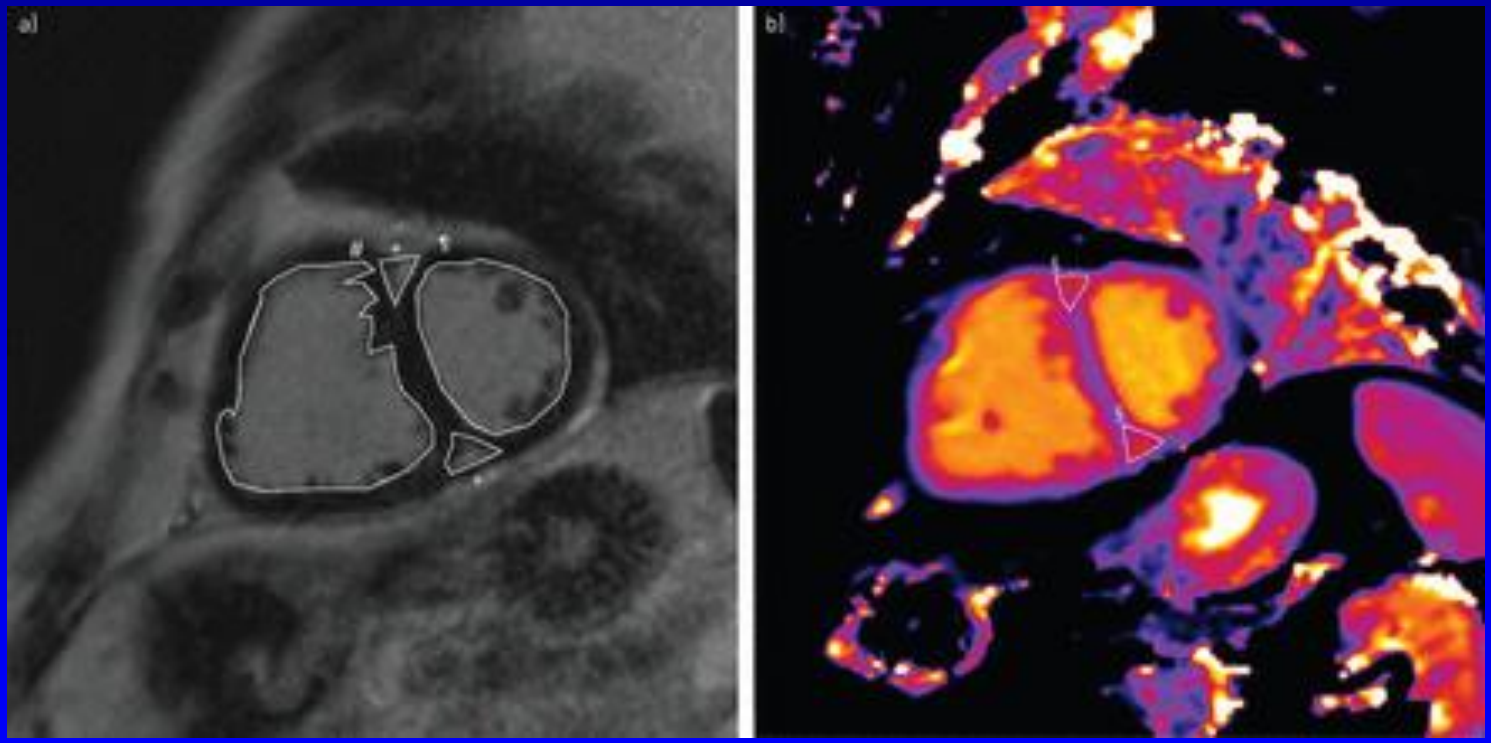
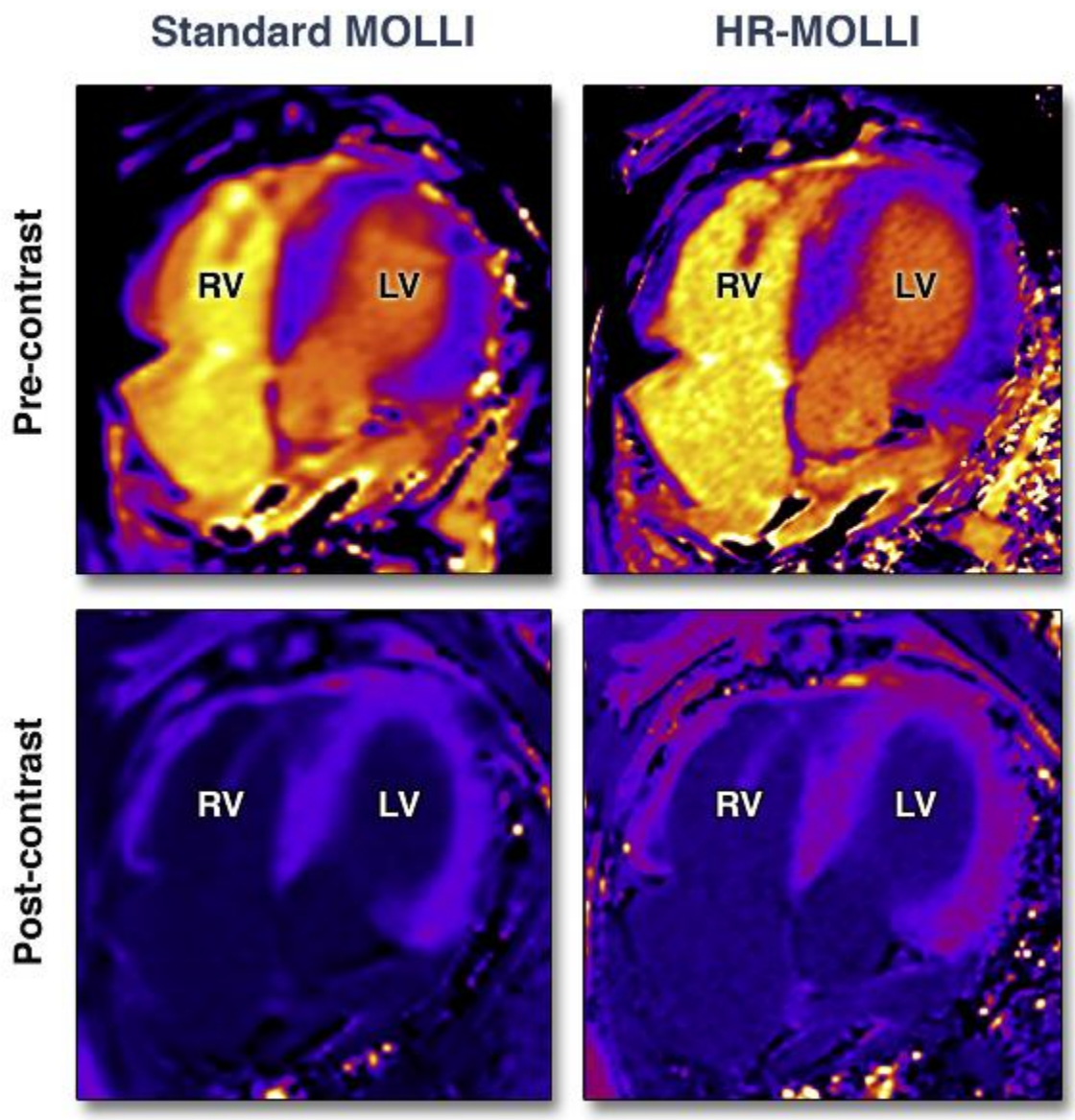


FIGURE 3 RV T_1 Mapping on CMR



LV Myocardial Fibrosis, Atrophy, and Impaired Contractility in Patients With Pulmonary Arterial Hypertension and a Preserved LV Function: A CMR study

- In patients with PAH, **changes in T1 and ECV** support the hypothesis of LV myocardial fibrosis and atrophy.
- This leads to an **impaired contractility despite a preserved LV function**, possibly due to longstanding PAH-associated LV underfilling.

Homsi R et al. J Thorac Imaging. 2017

The impact of ambrisentan and tadalafil upfront combination therapy on cardiac function in scleroderma associated pulmonary arterial hypertension patients: CMR feature tracking study.

- Upfront combination therapy with ambrisentan and tadalafil on LV, RV function in patients with systemic sclerosis-associated pulmonary arterial hypertension (SSc-PAH).

- LV and RV peak longitudinal and circumferential strain and strain rate (SR), which consisted of peak systolic SR (SRs), peak early diastolic SR (SRe), and peak atrial-diastolic SR (SRa) were analyzed using CMRI).

- Combination therapy was associated with a significant improvement in both RV-LV function as assessed by CMR-derived strain and SR.

Sato T et al. Pulm Circ. 2018

Stress CMR

Exercise CMR allows differentiation of low-risk pulmonary arterial hypertension

- **SV response in exercise was associated with disease severity.**
- **WHO FC I and RVEDV <221 ml were associated with increased SV during exercise (WHO FC I: 7% increase in SV; p < 0.001).**
- **In contrast, WHO FC II was associated with an 8% decrease in SV (p = 0.02), and SV response declined progressively with right ventricular dilation (7-ml decrease in SV per 100-ml increase in RVEDV; p < 0.001).**

Göransson C et al. J Heart Lung Transplant. 2019

Right ventricular perfusion

- Decline in RV coronary perfusion and subsequent RV ischemia.
- Coronary blood flow can be evaluated by stress CMR using gadolinium contrast and a coronary vasodilator such as adenosine or regadenoson or by PC-MRI techniques.
- Right coronary artery systolic flow in PAH patients was significantly decreased and correlated inversely with RV mass and RV pressure, compared with controls.
- Myocardial perfusion reserve index (MPRI) was significantly decreased for both the LV and RV, compared to controls

Final conclusions

TABLE 2 Key Parameters on MRI in the Evaluation of Patients With PH

	MRI Sequence Details	Key Points
RV size and function	bSSFP ECG-gated cine Short-axis or transaxial plane	Reference standard Delineation of tricuspid valve plane challenging on short-axis imaging Superior reproducibility makes it ideal for clinical trials SV, RVEF, RV volumes are all prognostic variables in PH
Interventricular septal changes	bSSFP ECG-gated or real-time cine imaging Short-axis plane	Provides insight into degree of RV pressure and volume overload Septal shift during cardiac cycle prognostic marker in PH
PA pulsatility (relative area change)	2D PC-MRI GRE or bSSFP ECG-gated cine	PA pulsatility prognostic marker in PH
PA mean transit time	TR-MRA	Significant prognostic marker in PH MRA is also helpful in differentiating between COPD, interstitial lung disease, and chronic thromboembolic disease
RVIP delayed enhancement	LGE	RVIP associated with worse outcomes in PH
RV diffuse interstitial abnormalities	RV T_1 mapping	RV interstitial abnormalities potentially identify diffuse fibrosis within the RV
RV strain	Myocardial tagging HARP DENSE SENC Feature tracking Deformation field analysis	Provides RV longitudinal, circumferential, and radial strain measurements Changes in regional strain potentially useful in understanding mechanism of disease
RV perfusion	First pass perfusion Vasodilator needed for stress perfusion	Detects changes in RV coronary flow Significant difference in these markers between PH patients and control subjects
PA peak velocity PA average flow PA time-to-peak velocity PA velocity-rise gradient PA and RV vortex flow PA wall shear stress	2D PC-MRI 4D-flow MRI	Significant differences in these markers between PH patients and control subjects Altered flow patterns recognized in the PA of PH patients Wall shear stress lower in PH patients compared with control subjects

2D = 2-dimensional; 4D = 4-dimensional; bSSFP = balanced steady-state free precession; DENSE = displacement encoding with stimulated echoes; ECG = electrocardiogram; GRE = gradient-recalled echo; HARP = harmonic phase analysis; LGE = late gadolinium enhancement; MRA = magnetic resonance angiography; MRI = magnetic resonance imaging; PC = phase contrast; RV = right ventricle; RVEF = right ventricular ejection fraction; RVIP = right ventricular insertion point; SENC = strain encoded imaging; SV = stroke volume; TR = time resolved; other abbreviations as in Table 1.

Transform crisis into inspiration