심장학회 춘계통합학술대회, 춘계 심초음파 학회 Apr 18, 2008

Tissue Characterization with *Cardiac Magnetic Resonanace Imaging*

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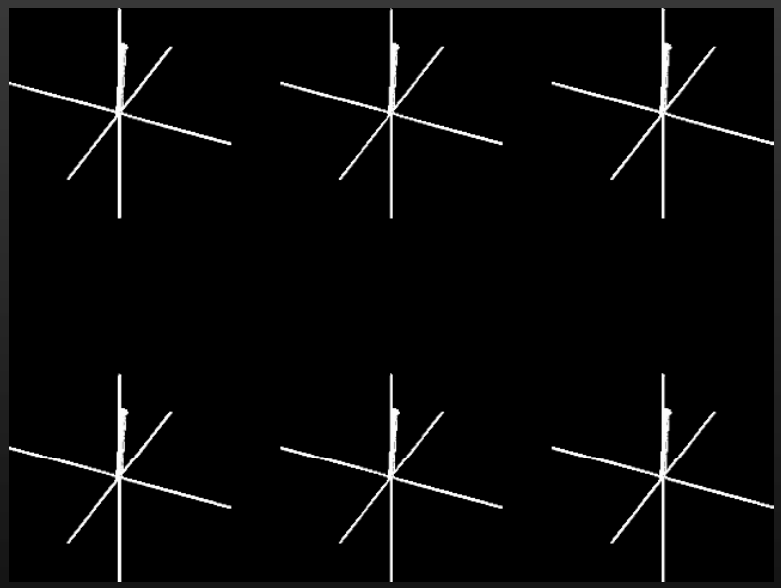
Tissue characterization

- Physics to understand tissue characterization with MRI
- Contrast-materials
- Clinical application



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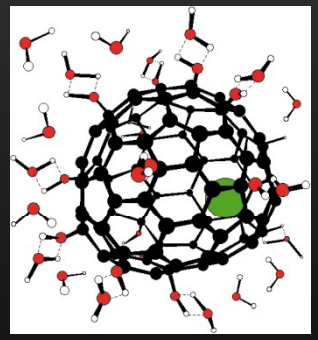
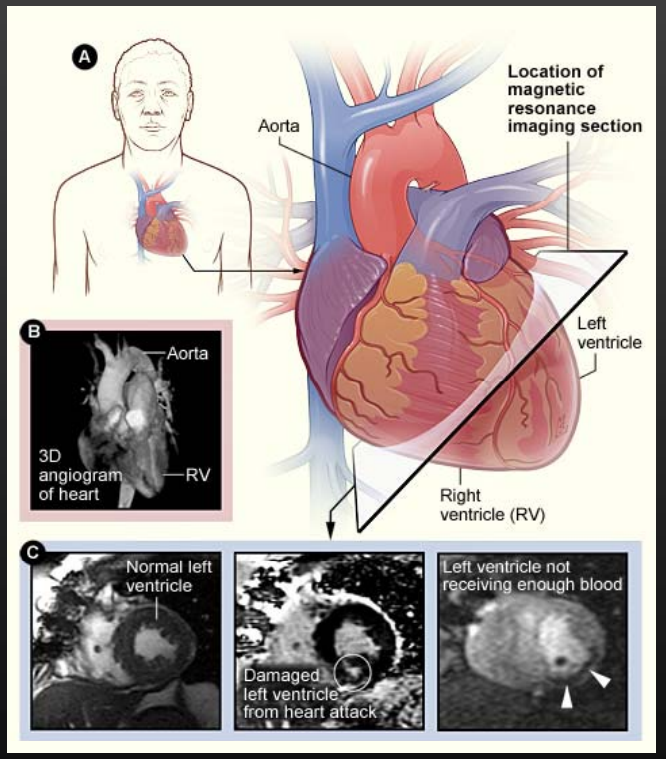


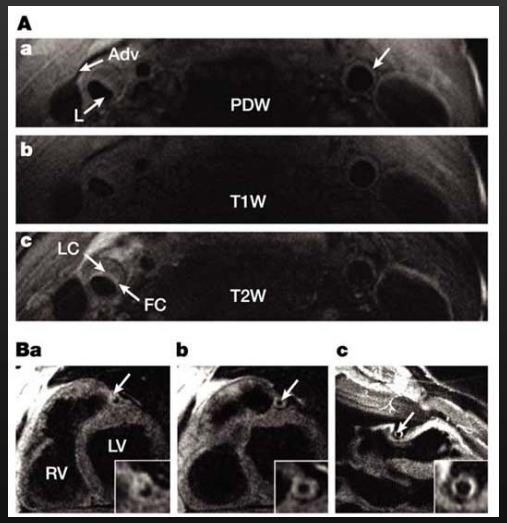
www.ruf.rice.edu



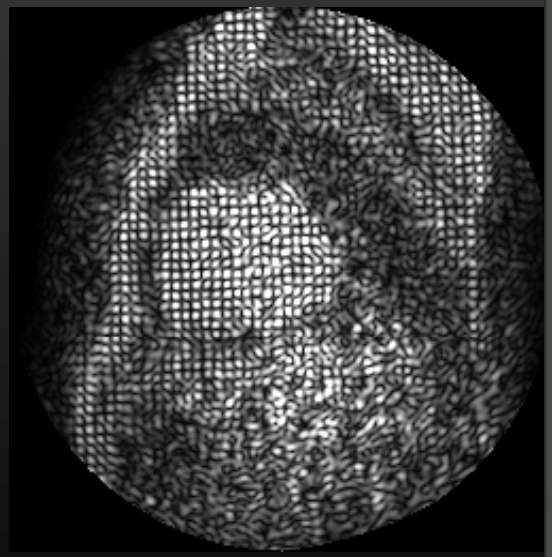
www.nhlbi.nih.gov

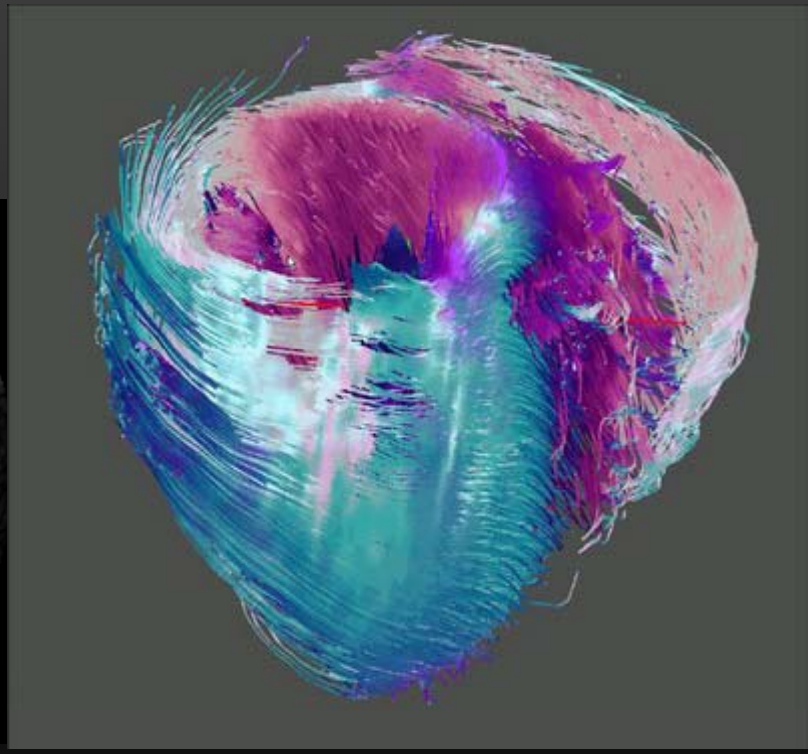
Tissue Characterization: CMR

- T1-weighted, T2-weighted, Proton density, Gradient echo
- Susceptibility artifact, Chemical shift artifact, Cancellation artifact,
- Paramagnetic effect
- Time of flight/ Velocity encoding/ Tagging/
- Spectroscopy/ Diffusion tensor imaging



Fayad et al. Circulation 2000;102:506



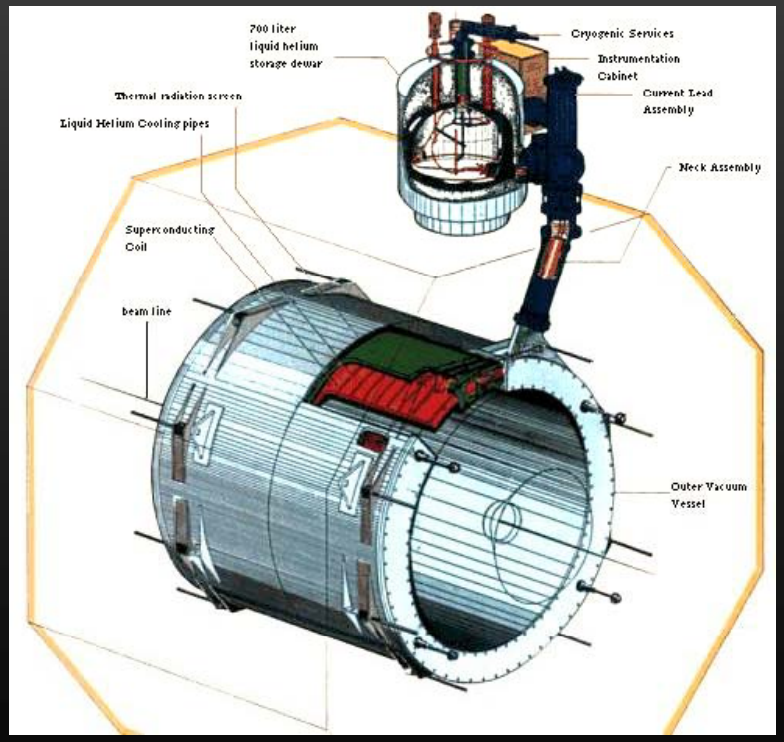


www.gg.caltech.edu

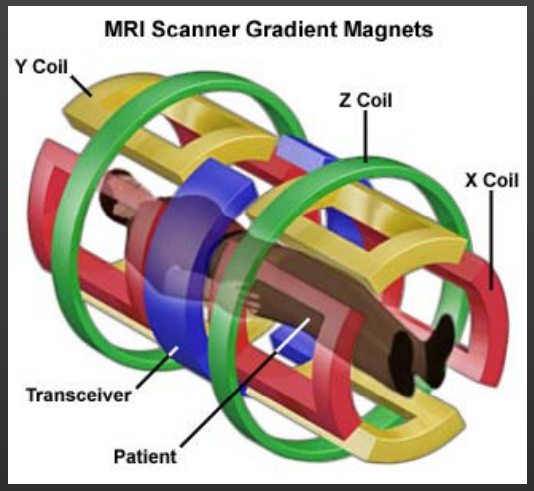
MRI Equipment

- Superconducting Magnet
- Gradient Coils
- RF coils
- Receiver Coils

www.magnet.fsu.edu



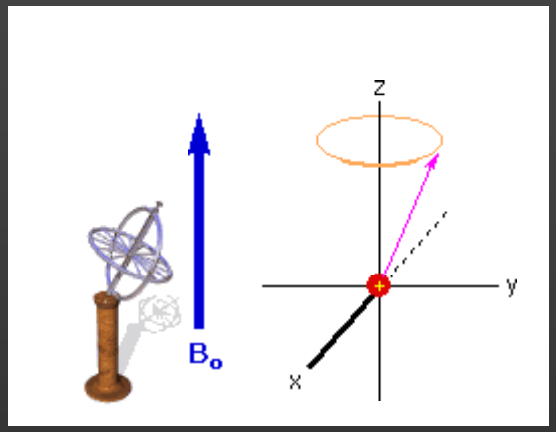
universe-review.ca

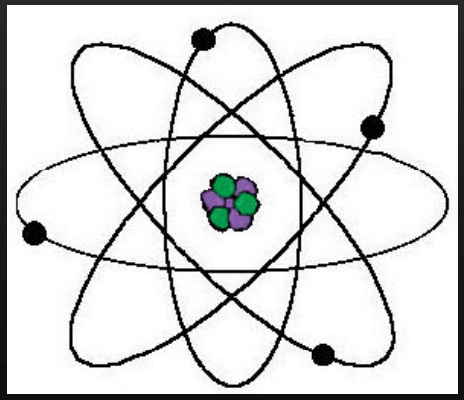


MR Principle

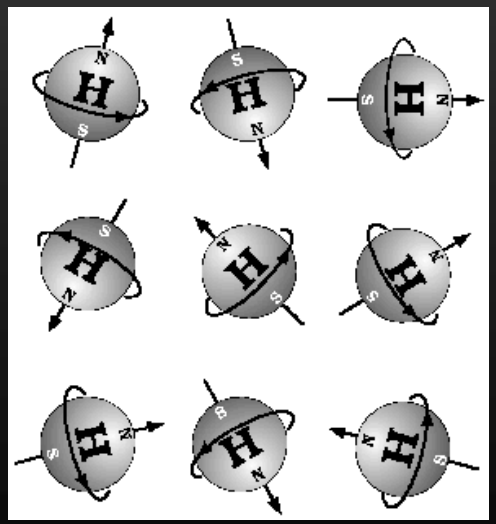
- Atom structure
  - Central nucleus: proton, neutron
  - Orbiting electrons
- Atom movement
  - Precession
- MR active nucleus
  - Alignment to an applied magnetic field
  - Magnetic momentum of nucleus
  - Only nuclei with odd number
  - Ex) Hydrogen 1
    Phosphorous 31

- Net Magnetic Vector (NMV)
- External magnetic field (B0)
- Strength of magnetic field
  - 1 tesla = 10,000 gauss
- Alignment
  - Parallel
  - antiparallel

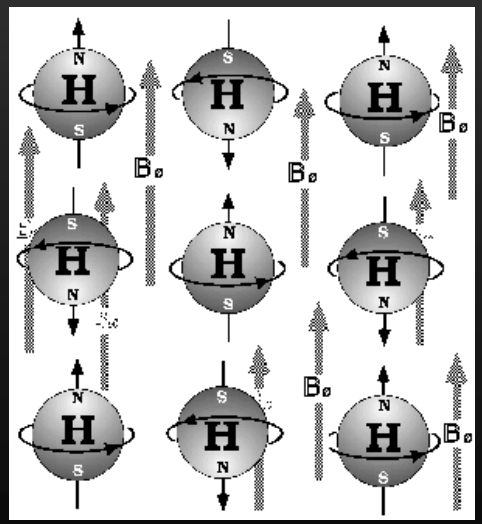




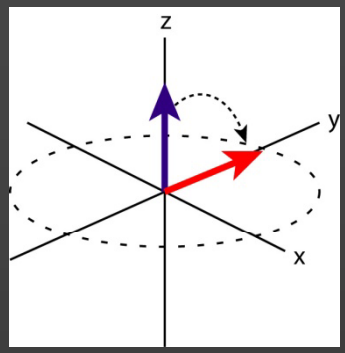
media.nasaexplores.com



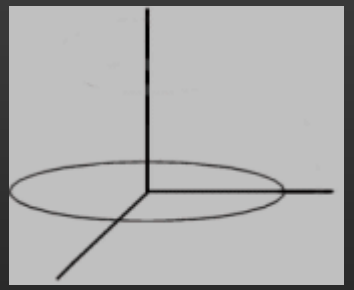
B0

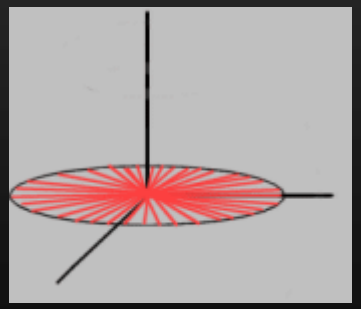


- Precession frequency (MHz)
- Larmour Equation
  - W0=B0 x gyro magnetic ratio
  - Hydrogen 63.86MHz under 1.5 T
- Resonance
  - Precession frequency at 90 degree to the B0
  - Radiofrequency band, RF pulse
- Excitation
  - Change direction of NMV
  - In phase
- Free Induction Decay
  - Relaxation – exponential process
  - T1 Recovery (spin lattice relaxation)
  - T2 decay (spin spin relaxation)
  - Dephasing
  - T1 & T2 time : 63%
  - Different T1 and T2 in fat and water
- Receiver Coil
  - Signal : voltage induced

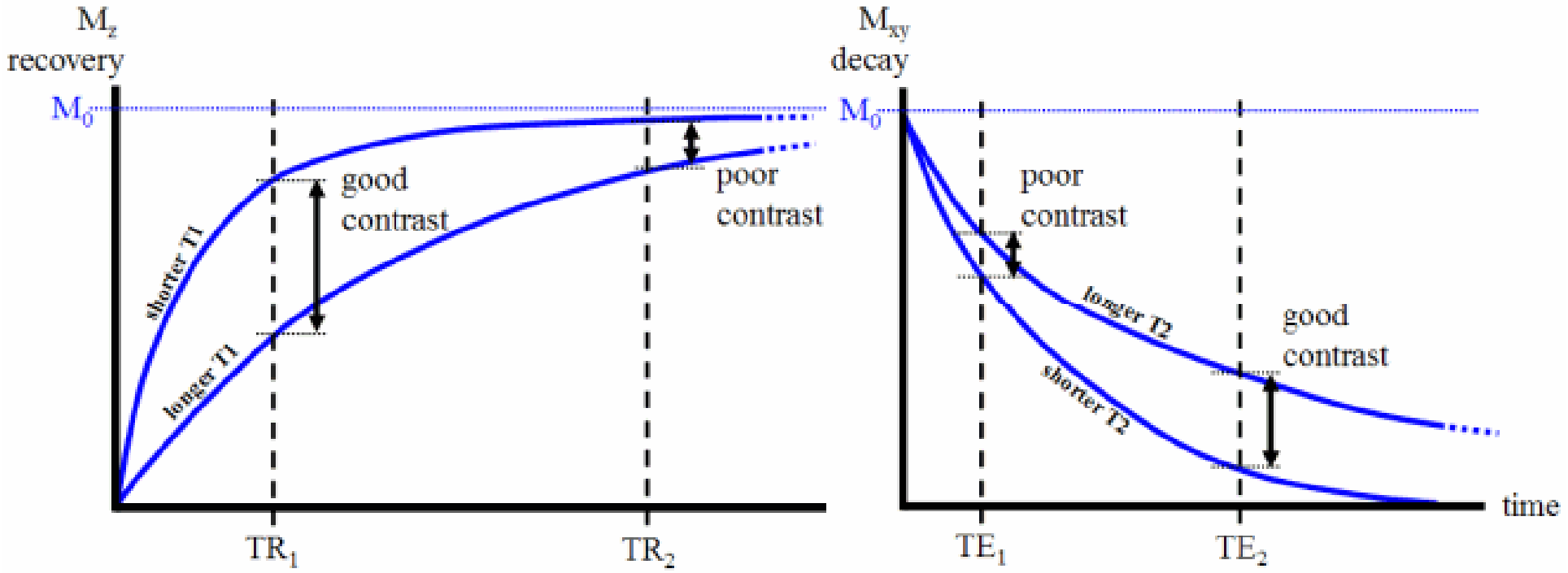


www-mrsrl.stanford.edu





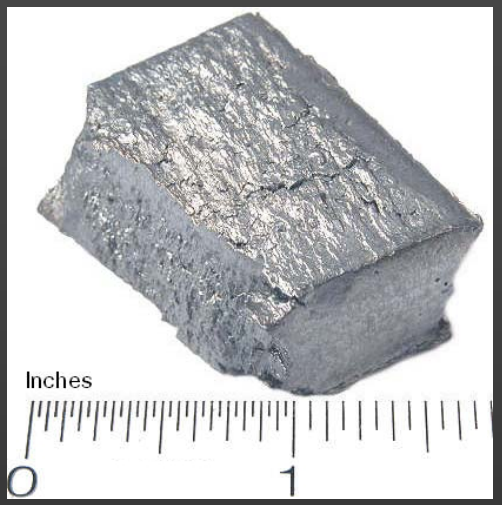
www.hull.ac.uk

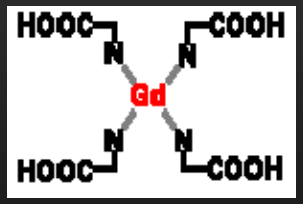

M_z
recovery
M_0
shorter T1
longer T1
good
contrast
poor
contrast
TR_1
TR_2
M_{xy}
decay
M_0
poor
contrast
longer T2
shorter T2
good
contrast
time
TE_1
TE_2

Contrast Agents

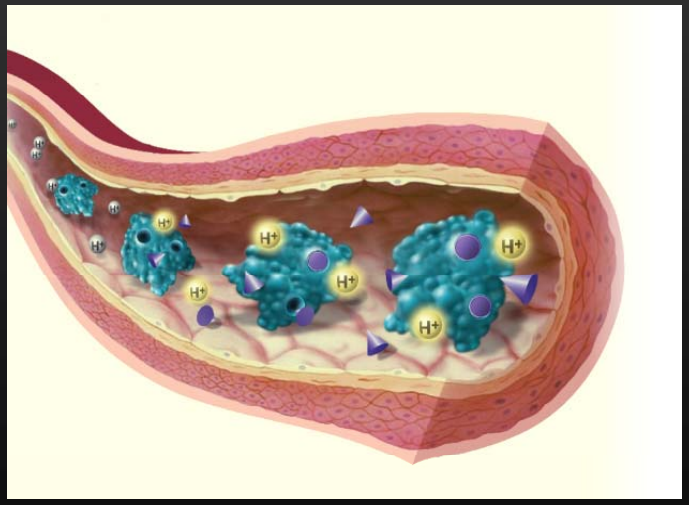
- Basic contrast by body contents of
  - ^{1}H, ^{23}Na, ^{31}P, Hyperpolarized ^{13}C-urea
- Contrast Agents
  - Paramagnetic metal
    - Gadolinium (Gd^{3+}), Manganese (Mn^{2+}), Dysprosium (Dy^{3+}), iron (Fe^{3+})
    - Intrinsic paramagnetic effect by hemoglobin
  - Superparamegnetic, ferromagnetic agents
    - Fe_3O_4

- Extracellular Contrast Agents
- Blood-Pool Contrast Agents
- Intracellular Contrast Agents
- Necrosis-Avid or Multipurpose Contrast Agents
- Plaque- and Thrombus-Specific Contrast Agents
- Molecular Imaging Contrast Agents

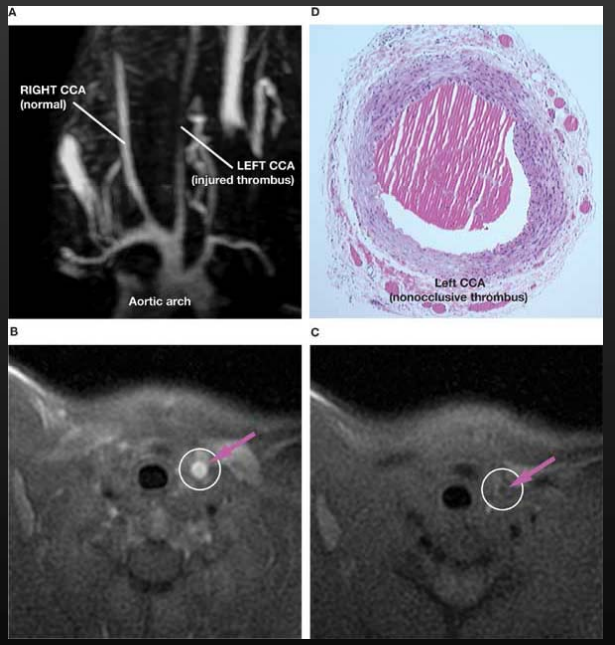




www.mritutor.org

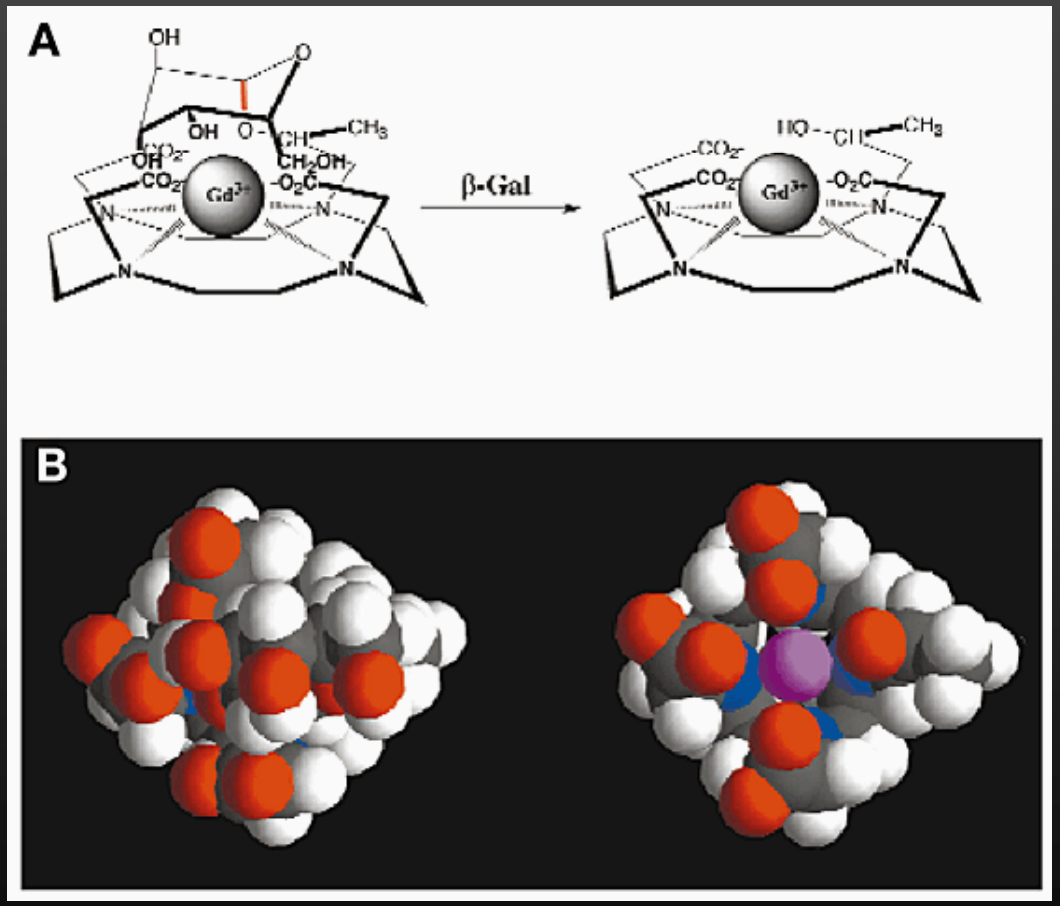


www.bloodpoolagents.com

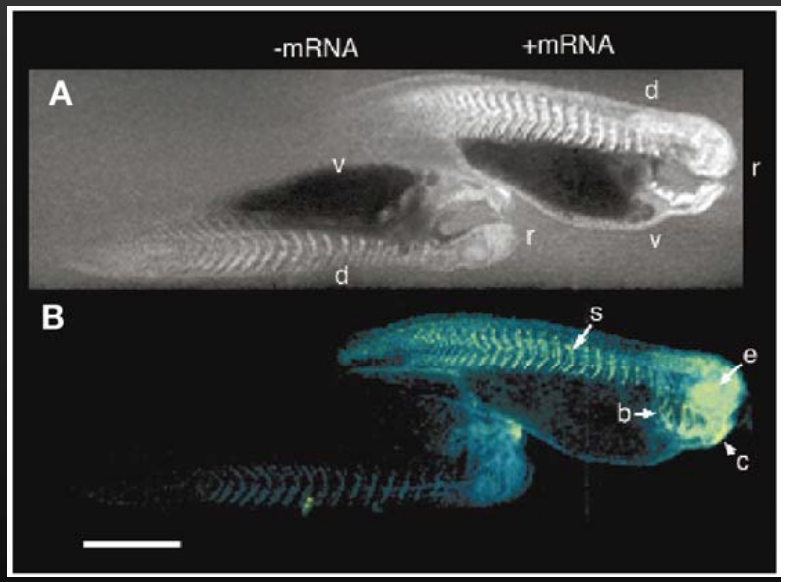


www.nature.com

Novel Contrast Agent (EgadMe)



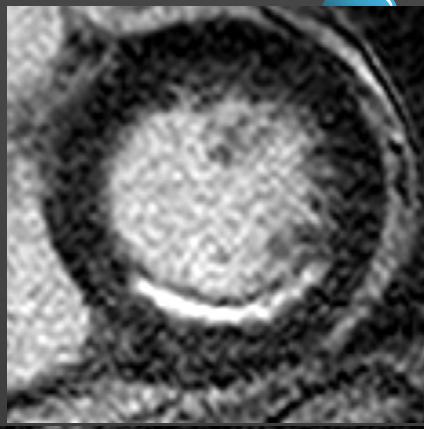
- Galactopyranosyl ring removed by beta-galactosidase (enzymatic cleavage)

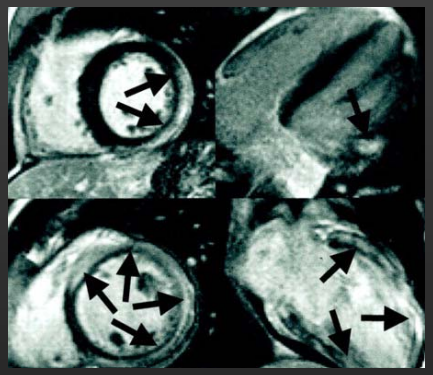


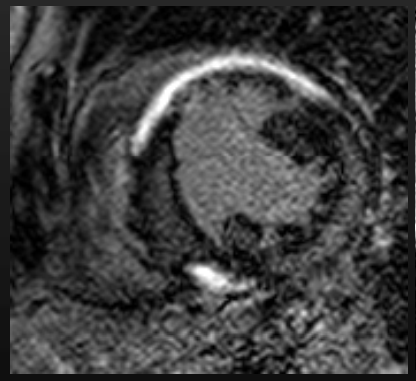
Louie et al. Nat Biotechnol 2000;18:321

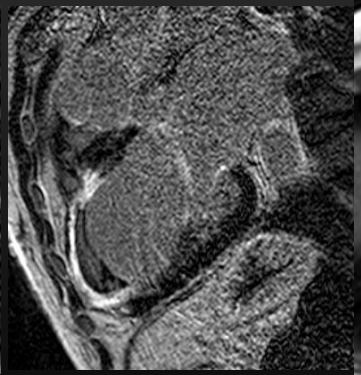
Clinical Application

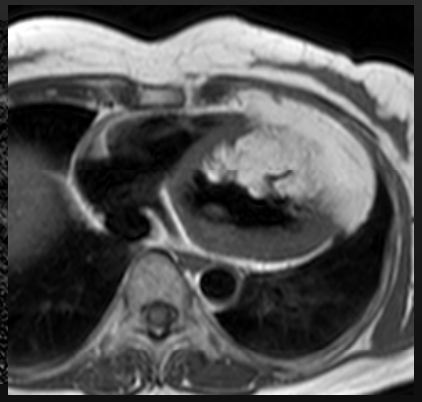
- Necrosis - Infarction
- Fibrosis – Scar, Fibroma
- Inflammation - Myocarditis
- Edema - AMI
- Hemorrhage – infarction, HCMP
- Thrombus vs. mass
- Multicontrast plaque imaging
- Fat – ARVD, lipoma

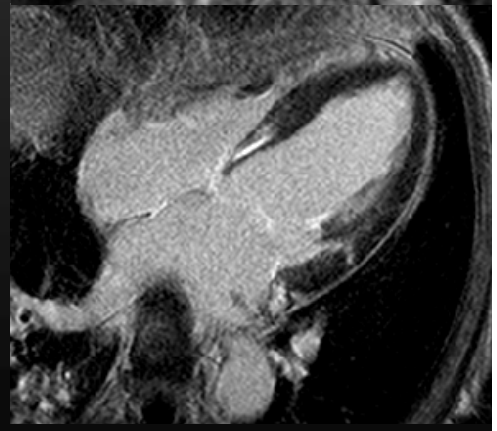






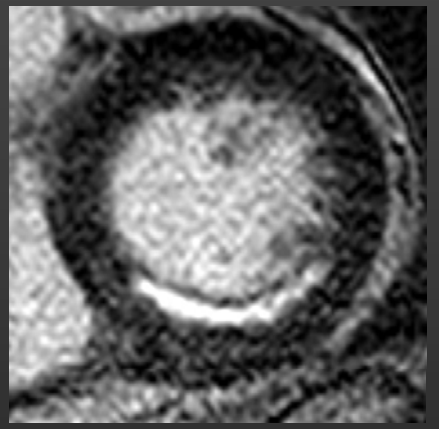






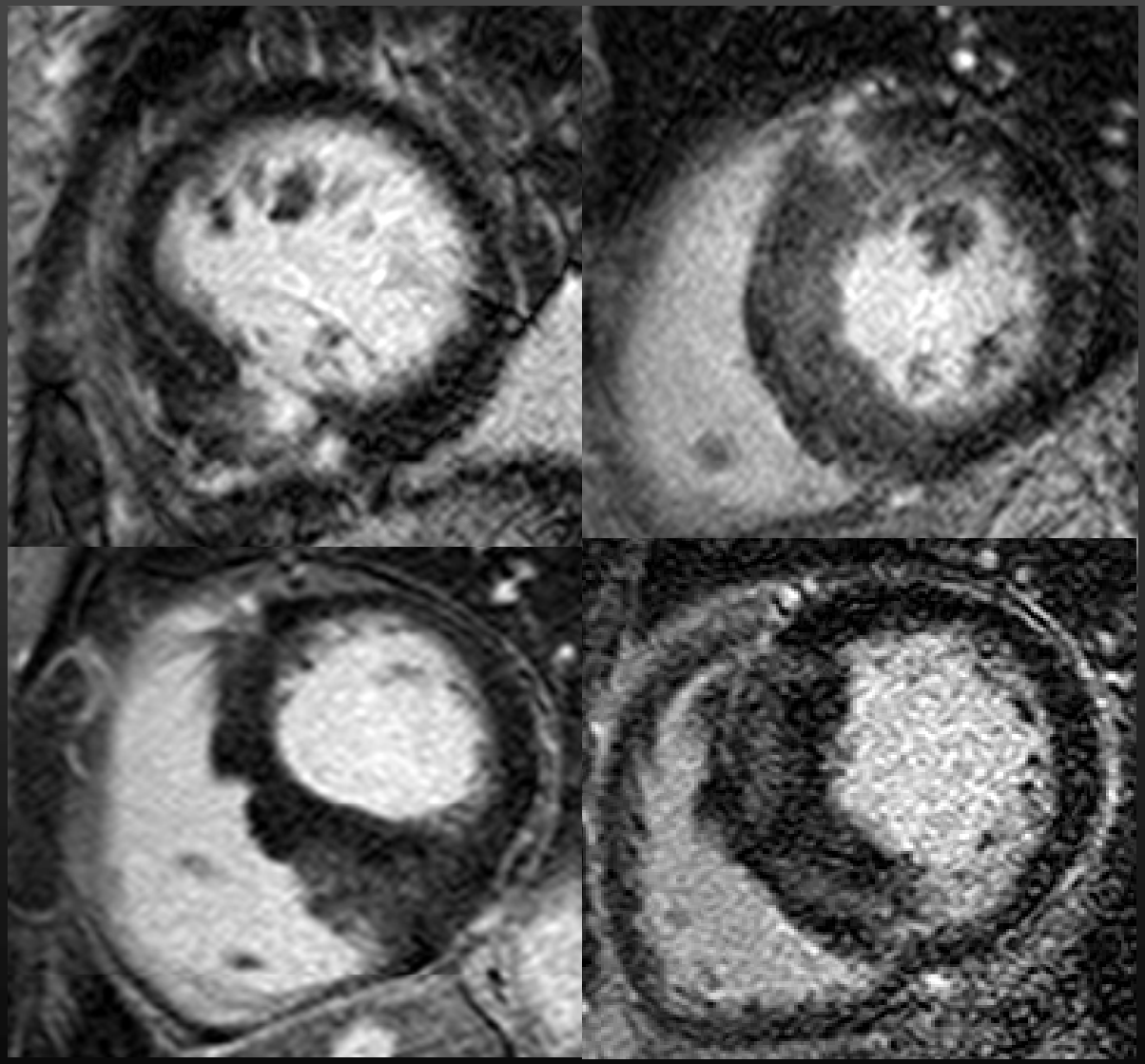
DE-MRI:
Clinical applications

- Subendocardial infarction
- LV thrombus
- No reflow zones
- Nonischemic cardiomyopathy
- Myocarditis and infiltrative cardiomyopathies
- Monitoring therapeutic interventions



HCMP: Myocardial Enhancement

- Mechanism and histology
  - Focal increased collagen content
    - Moon et al., 2004
  - Other than fibrosis
    - Knaapen et al., 2005
- Clinical Implication
  - Prognostic significance
    - Shirani et al., 2000
  - Sudden death
    - Moon et al., 2003
- Functional correlation
  - Correlation inversely
    - Choudhury et al., 2002



Midwall enhancement

- *McCrohon JA, et al. Circulation 2003; 108:54-59.*
- Delayed CE-MRI
  - HF with CAD
    - Subendocardial or Transmural
  - HF related DCMP
    - no enhancement (59%)
    - subendocaridal or transmural (13%)
    - *Patchy of longitudinal striae of midwall (28%)*

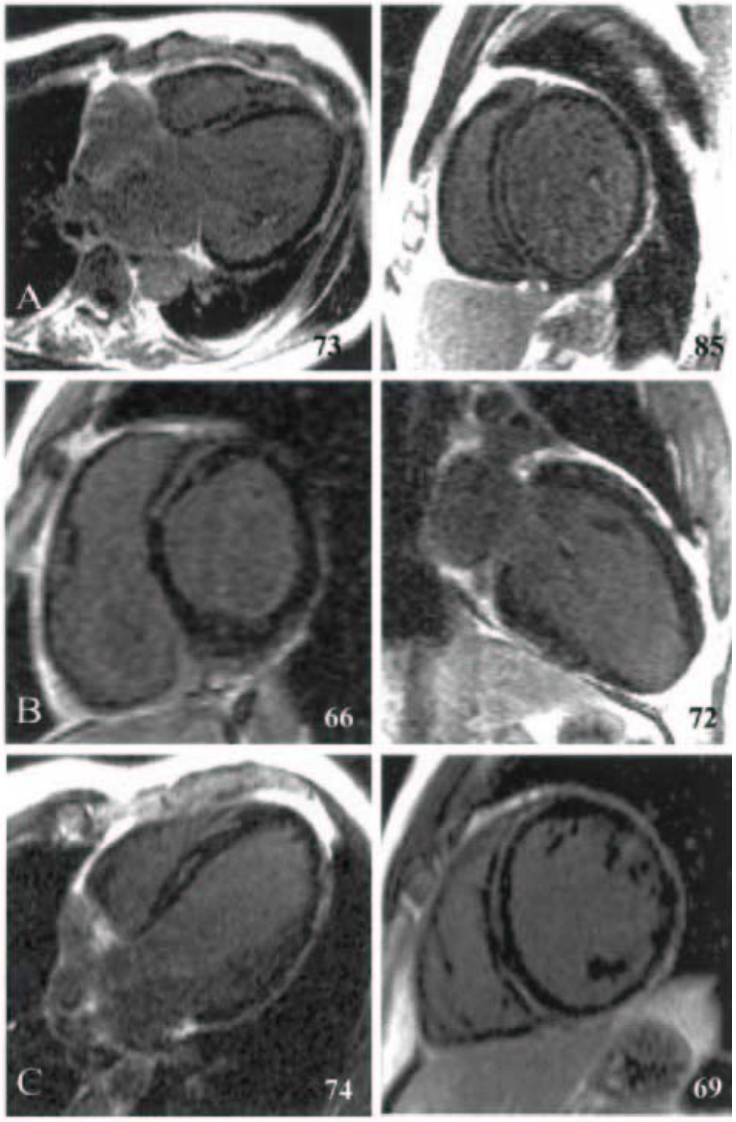


Figure 4. Three patients with DCM with midwall striae of enhancement (subgroup 3). Gadolinium enhancement followed ventricular longitudinal muscle fibers, particularly involving the septum and basal to mid-LV regions. Pattern is clearly different from patients with heart failure related to CAD. Abbreviations and numbers as in Figure 1.

Strong basal-septal middle-layer enhancement

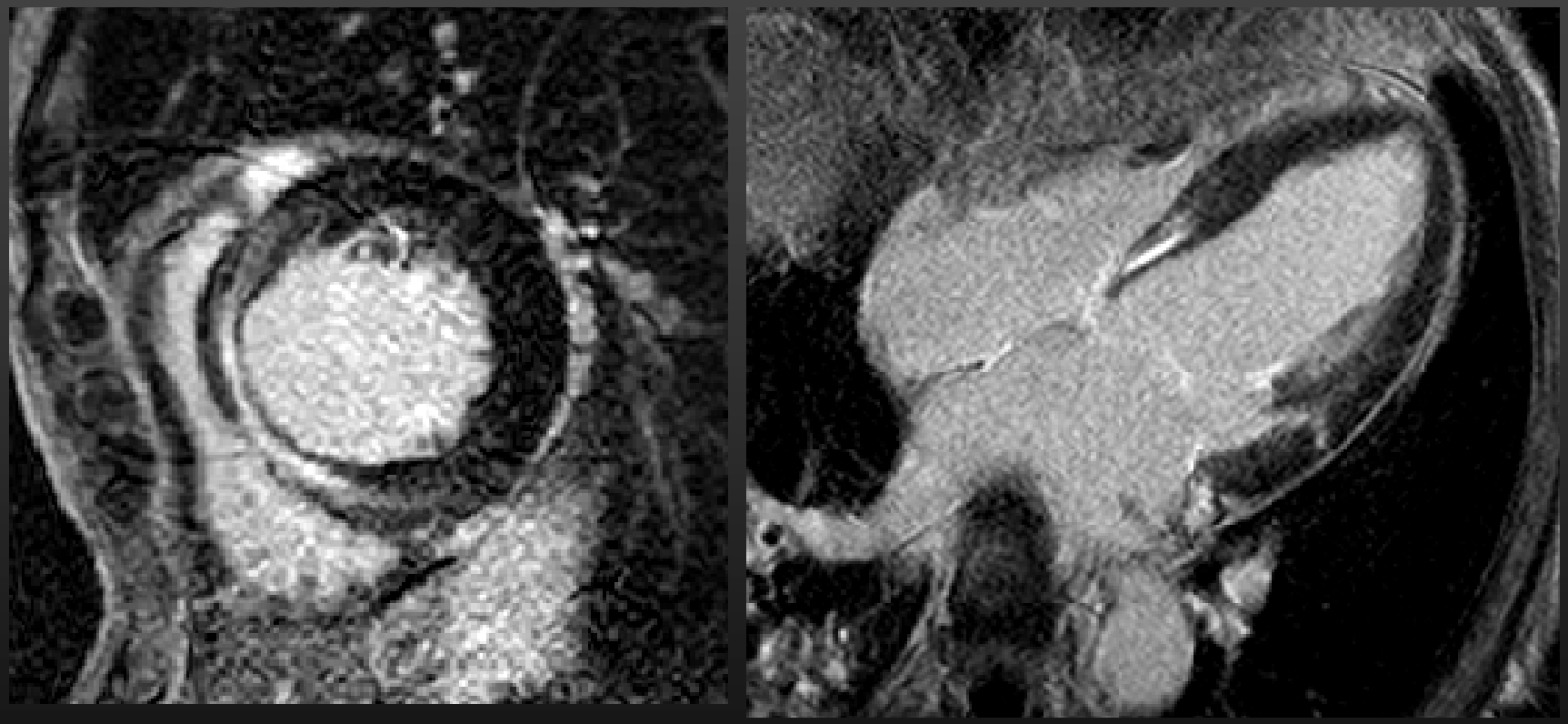


Table 2. Initial and Followup Echocardiography Data

	Group 1 (n = 24)	Group 2 (n = 22)	*P* Value*
Duration to followup echo (mo)	7.2 ± 2.8	9.0 ± 5.3	.145
Initial LVEDD (mm)	63.9 ± 6.1	67.2 ± 8.7	.146
Initial LVESD (mm)	55.3 ± 6.5	59.5 ± 8.7	.076
Initial LVEF (%)	28.3 ± 7.1	24.1 ± 7.2	.056
Initial RVSP (mm Hg)	33.8 ± 12.2	34.3 ± 13.2	.902
Significant MR (grade ≥2)	11 (45.8%)	10 (45.5%)	.763
Significant TR (grade ≥2)	6 (25.0%)	4 (18.2%)	.472
Follow-up LVEDD (mm)	56.2 ± 7.3	62.6 ± 11.9	.033
Follow-up LVESD (mm)	43.2 ± 9.2	52.8 ± 12.6	.005
Follow-up LVEF (%)	46.8 ± 12.4	31.6 ± 11.3	<.001
Follow-up RVSP (mm Hg)	28.4 ± 8.9	29.5 ± 10.0	.739
Δ LVEDD (change from baseline, mm)	−8.34 ± 5.92	−5.24 ± 7.39	.130
Δ LVESD (change from baseline, mm)	−12.83 ± 8.06	−7.38 ± 8.88	.039
Δ LVEF (change from baseline, %)	19.2 ± 13.8	7.5 ± 12.1	.004
Functional recovery (LVEF >45%)	19/24 (79.2%)	2/22 (9.1%)	<.001

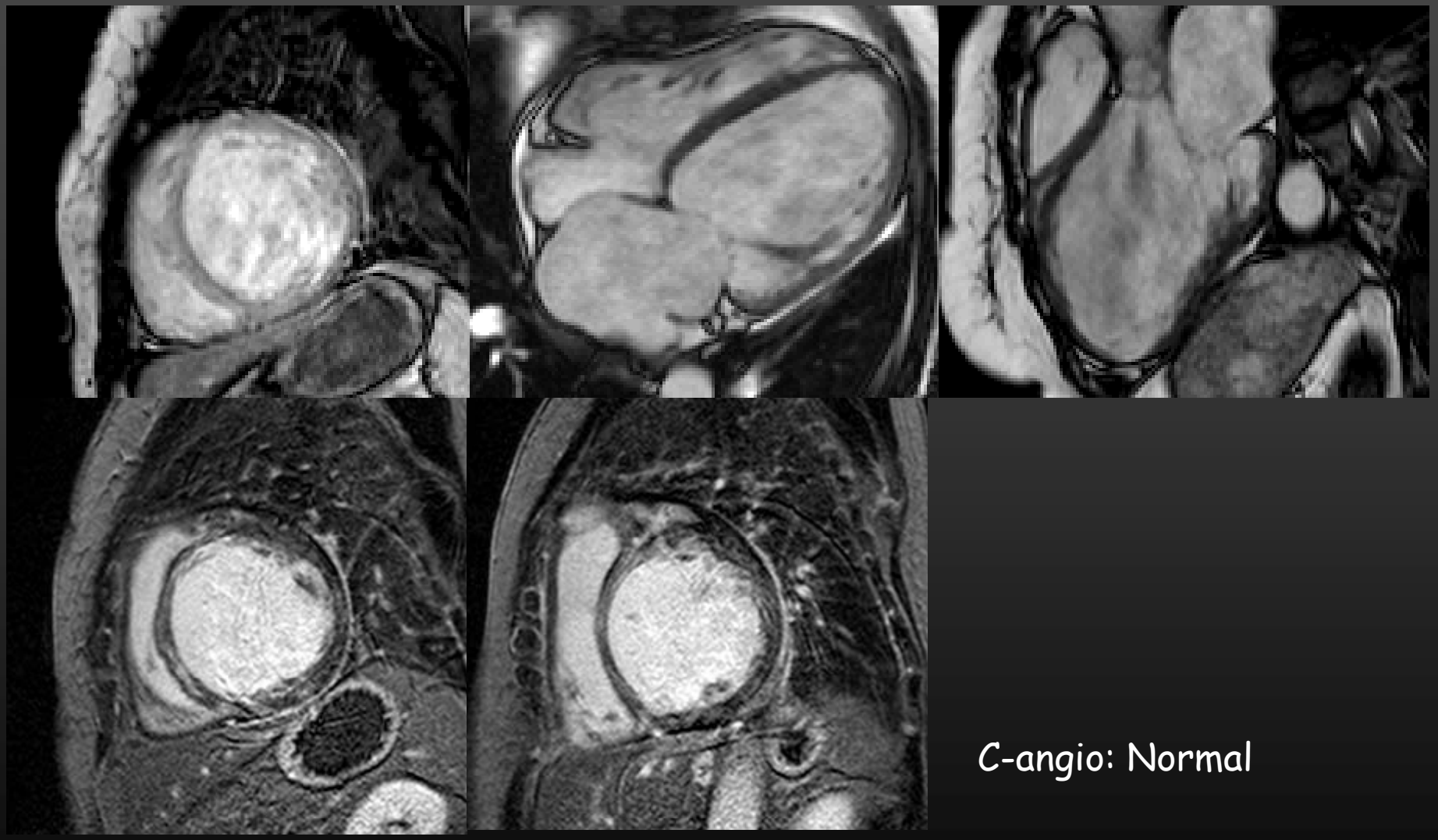
Group 1 indicates patients with absence of delayed hyperenhancement; group 2 indicates patients with delayed hyperenhancement.

$P < .05$ is considered significant.

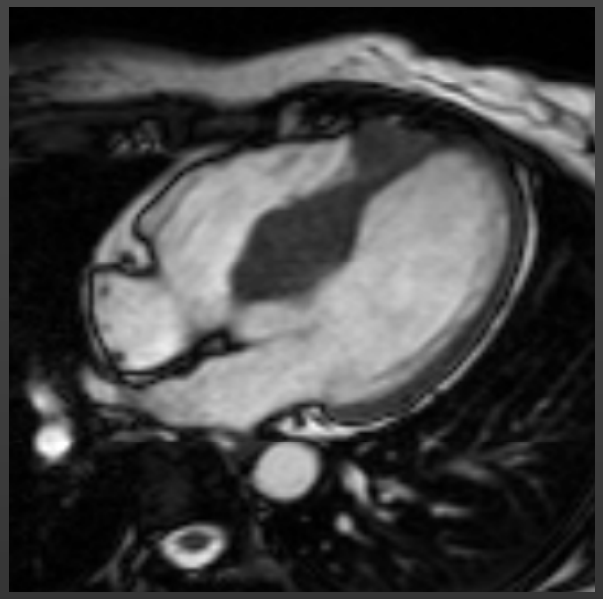
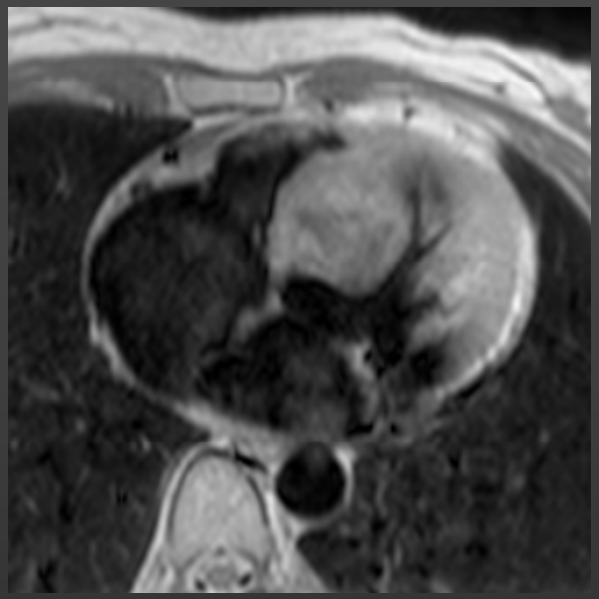
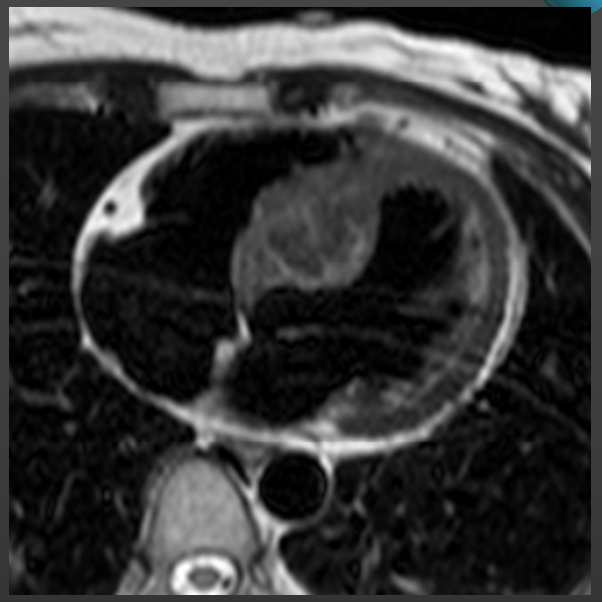
LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; RVSP, right ventricular systolic pressure; TR, tricuspid regurgitation.

Park et al. J Card Fail 2006;12:93

F/57
Dyspnea

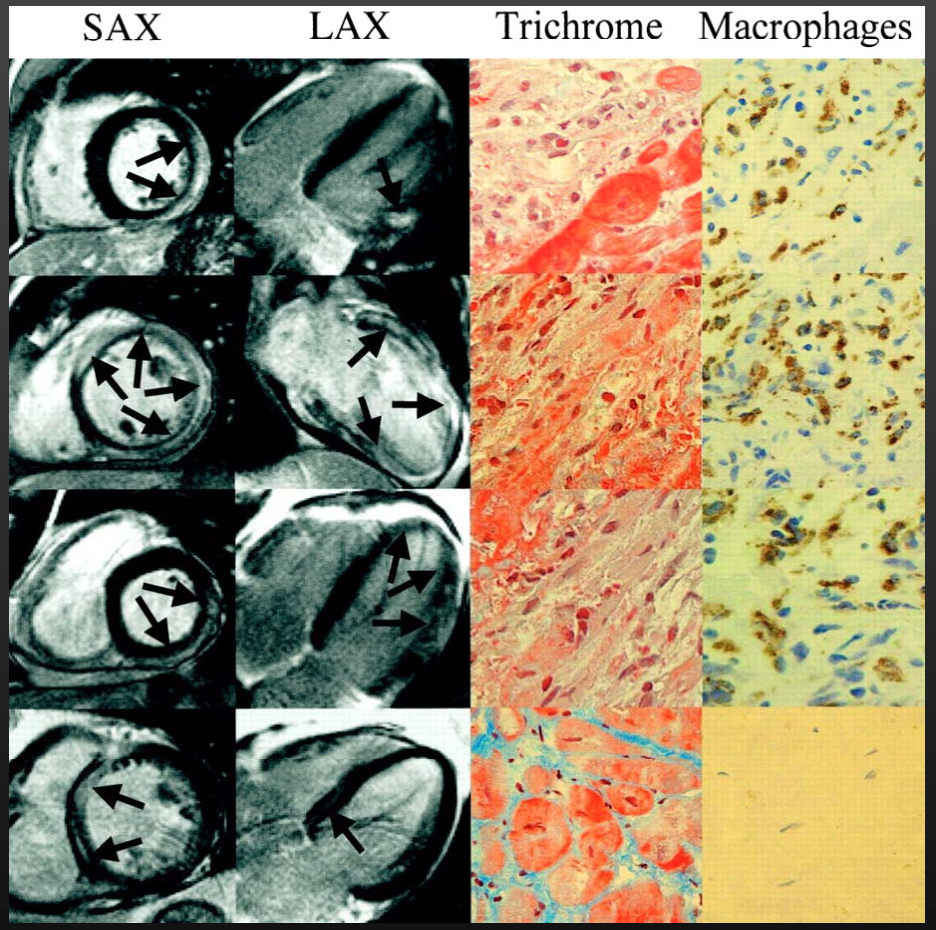


C-angio: Normal

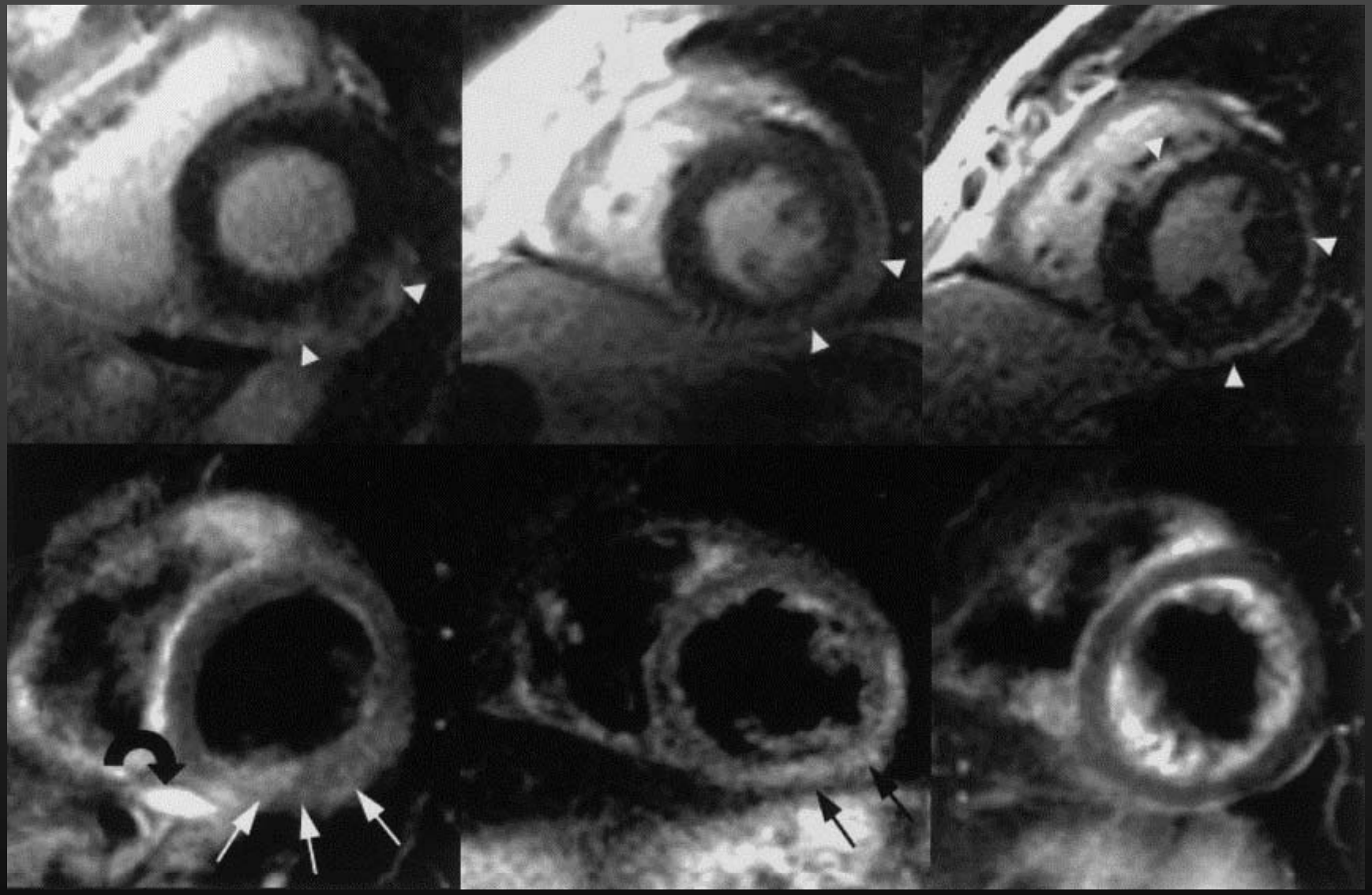




Myocarditis

- Inflammation in biopsy in DCM patients: 22%
- Endomyocardial Biopsy: sample error, variability in pathologic evaluation, potentially risky



- Mahrholdt et al. Circulation 2004;109:1250



- *Abdel-Aty et al. JACC 2005;45:1815*

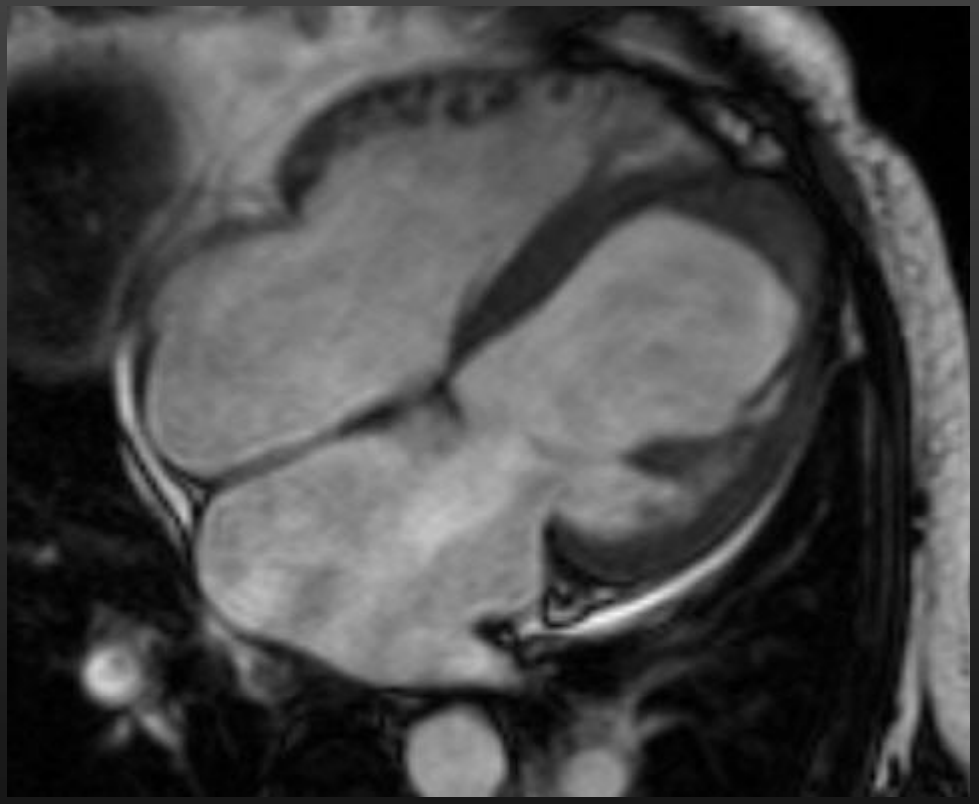
CMR in myocarditis

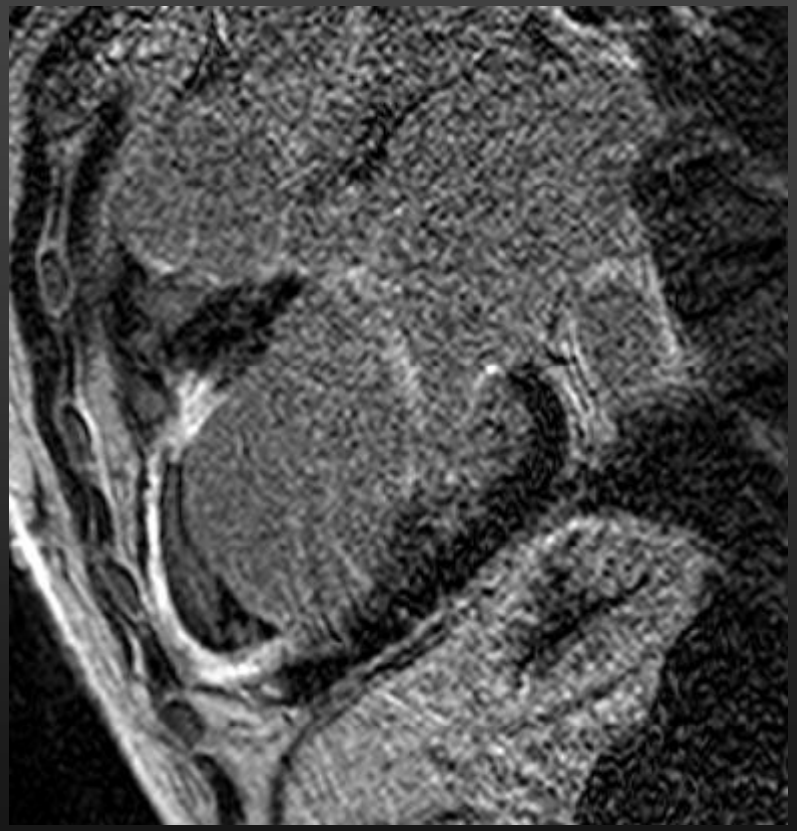
- Enhancement in 88% of patients
- Active myocarditis in 19/21 LGE biopsy
- Active myocarditis in 1/11 non-LGE biopsy
- 3 months f/u
  - LGE decrease 9% to 3%
  - LVEF increase 47% to 60%

Mahrholdt et al. Circ 2004

	Sensitivity	specificity	accuracy
T2 signal	**84%**	**74%**	**79%**
Global enhancement	**80%**	**68%**	**74.5%**
Late enhancement	**44%**	**100%**	**71%**

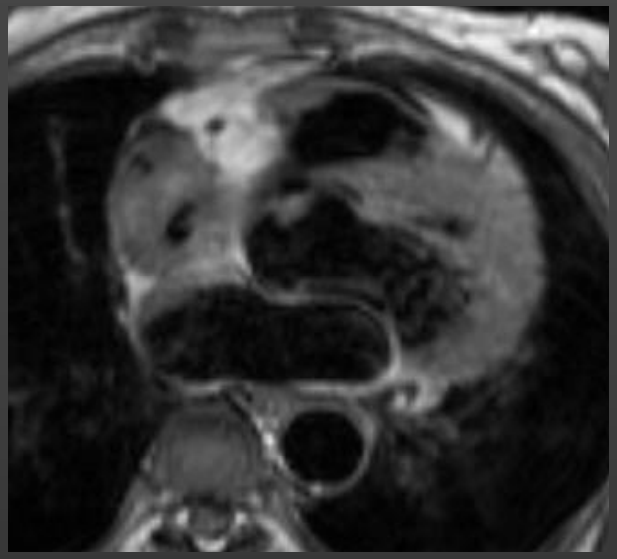
- *Abdel-Aty et al. JACC 2005;45:1815*



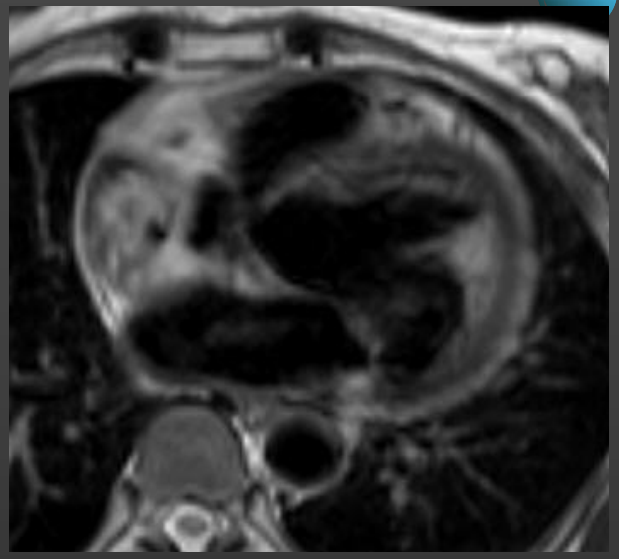


CT

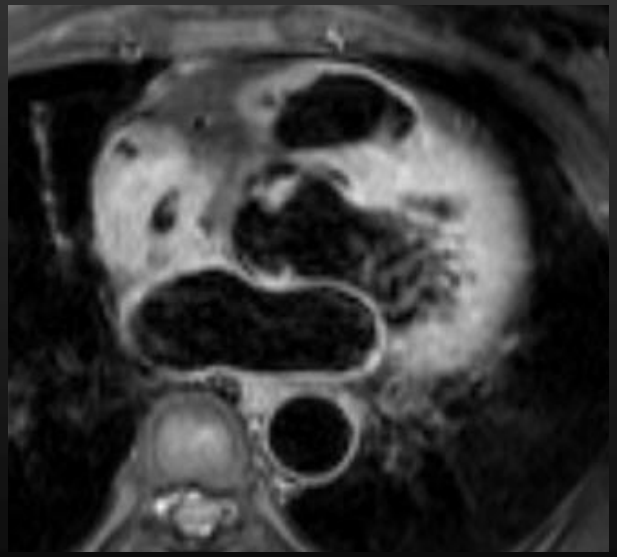
T1



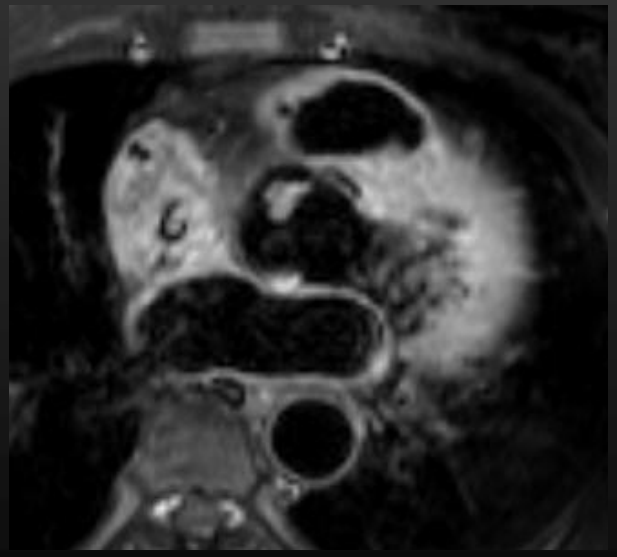
T2

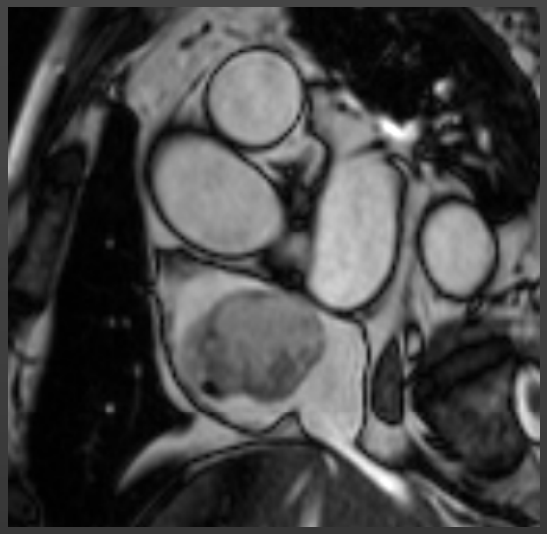


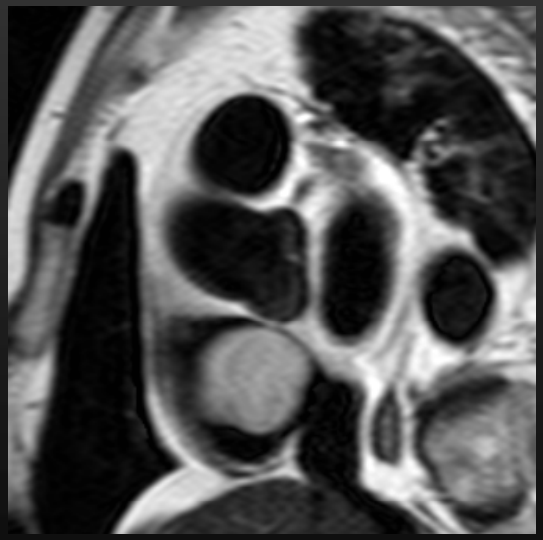
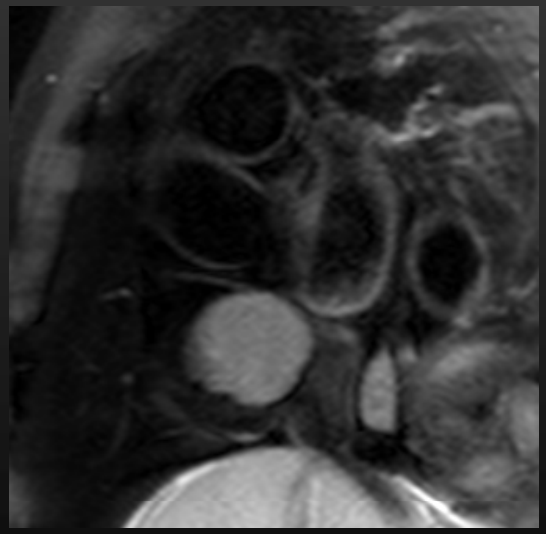
T1F-pre

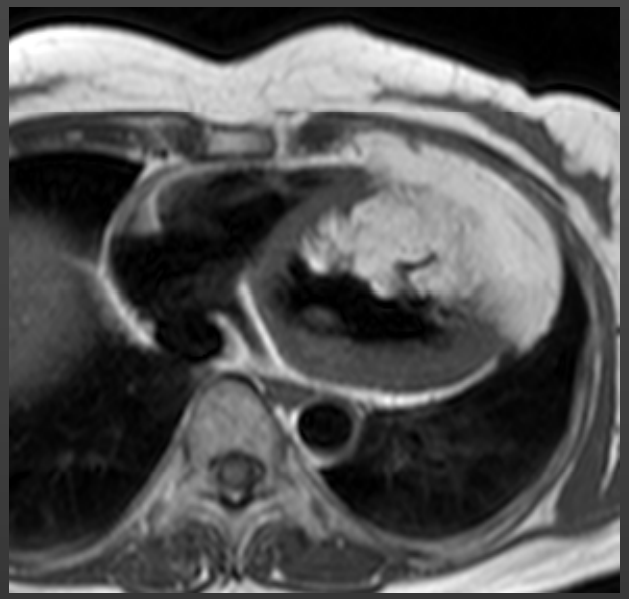


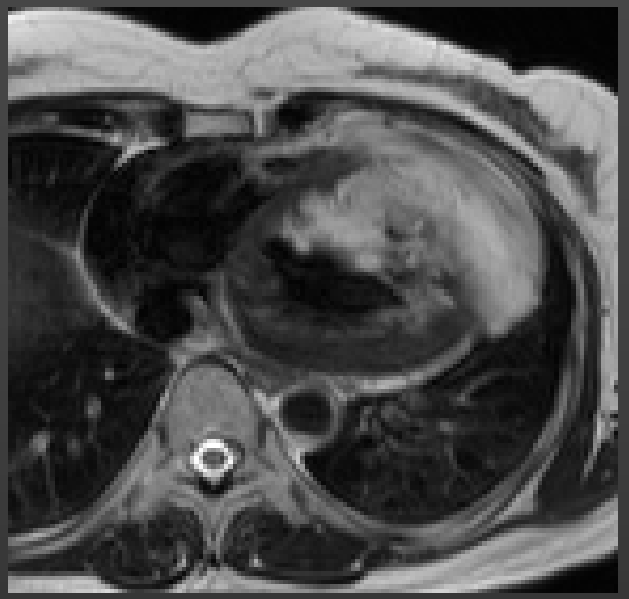
T1F-Gd

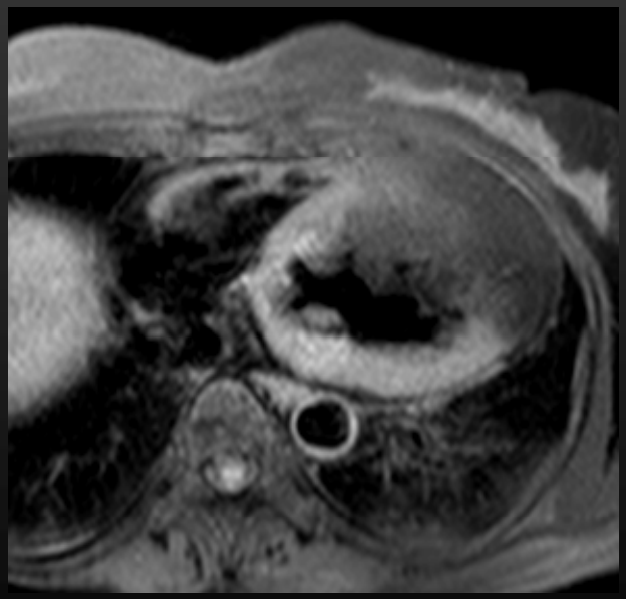


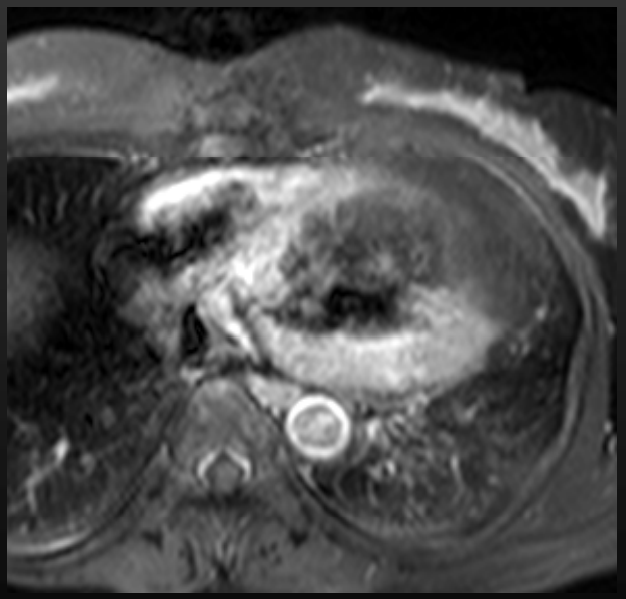


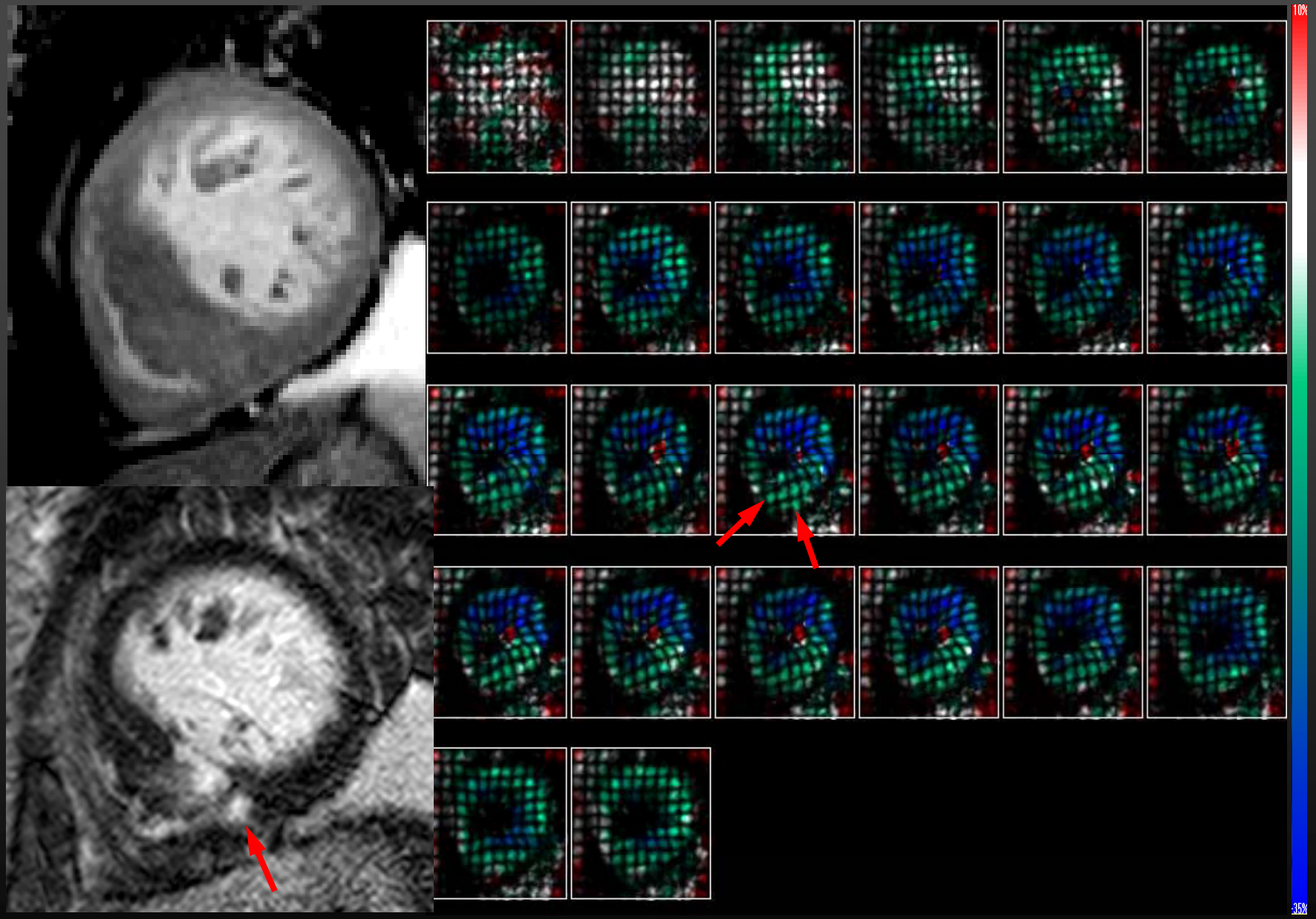







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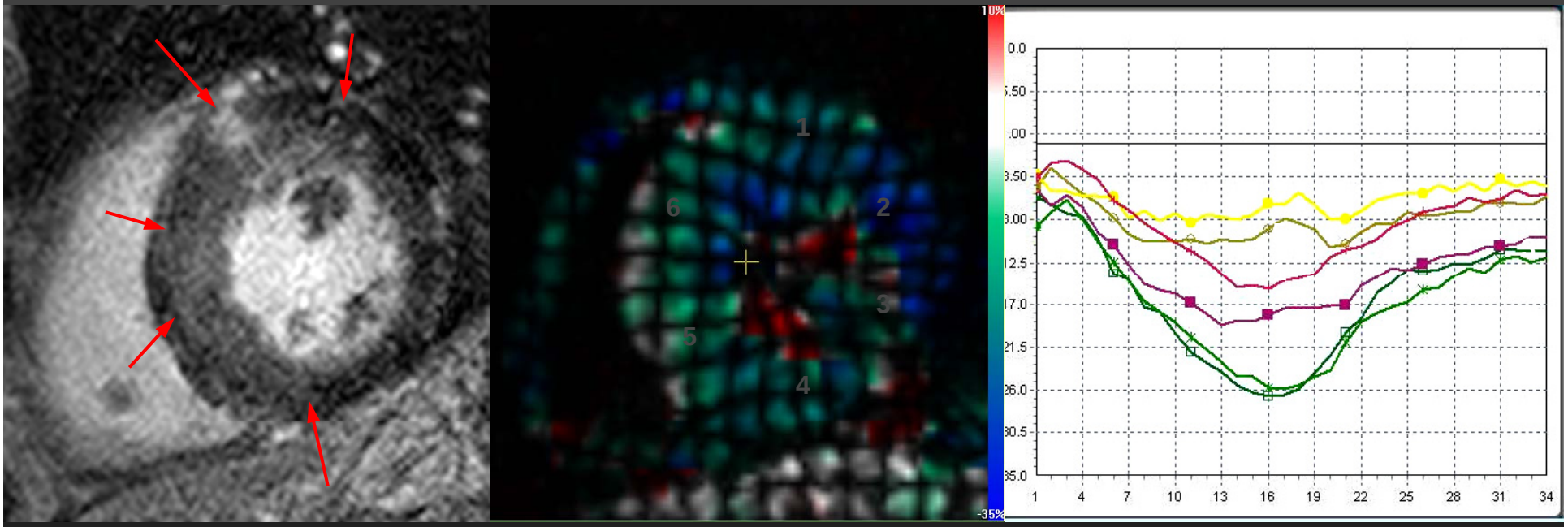
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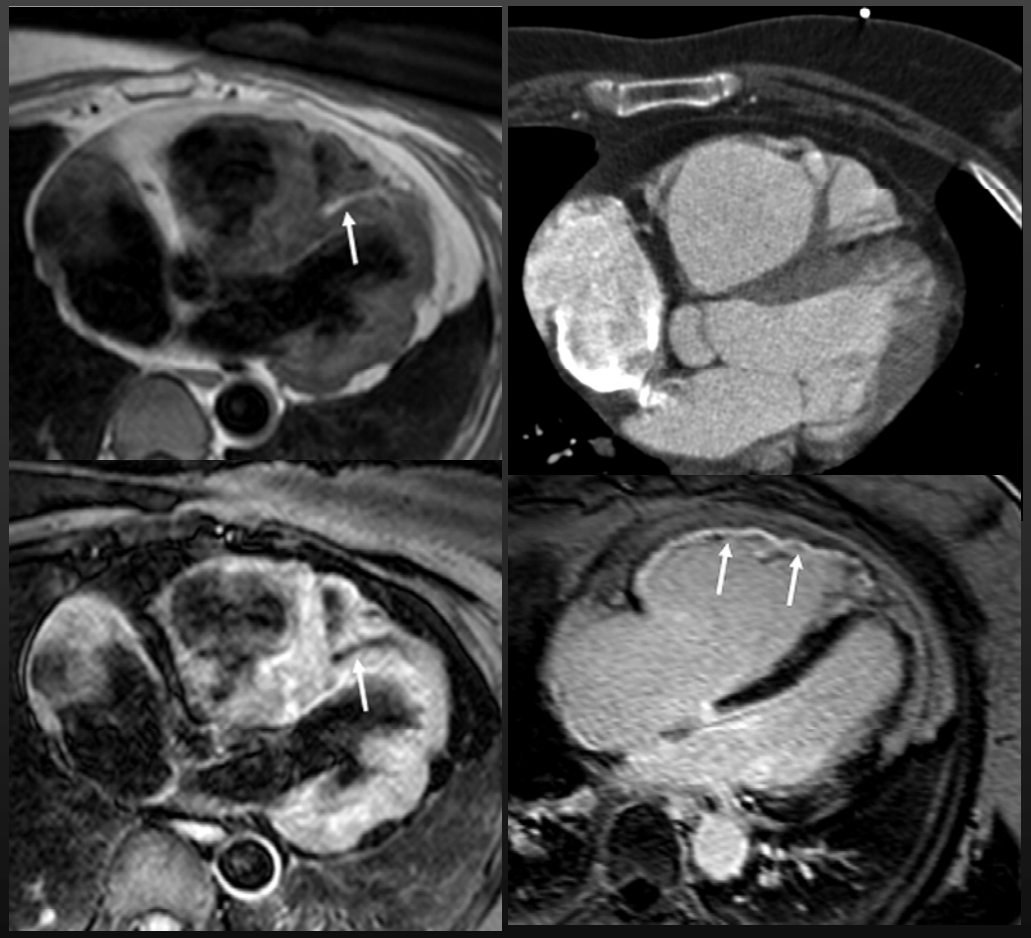
Arrhythomogenic Right Ventricular Dysplasia

- Intramyocardial fat
- Right ventricular wall thinning
- Right ventricular wall hypertrophy
- Trabecular disarray of the RV
- Enlargement of the RV outflow tract
- Detection of myocardial fibrosis
- Global RV dysfunction
- Regional RV dysfunction
- Diastolic dysfunction of the RV



- Maintz et al. Circulation 2006;113

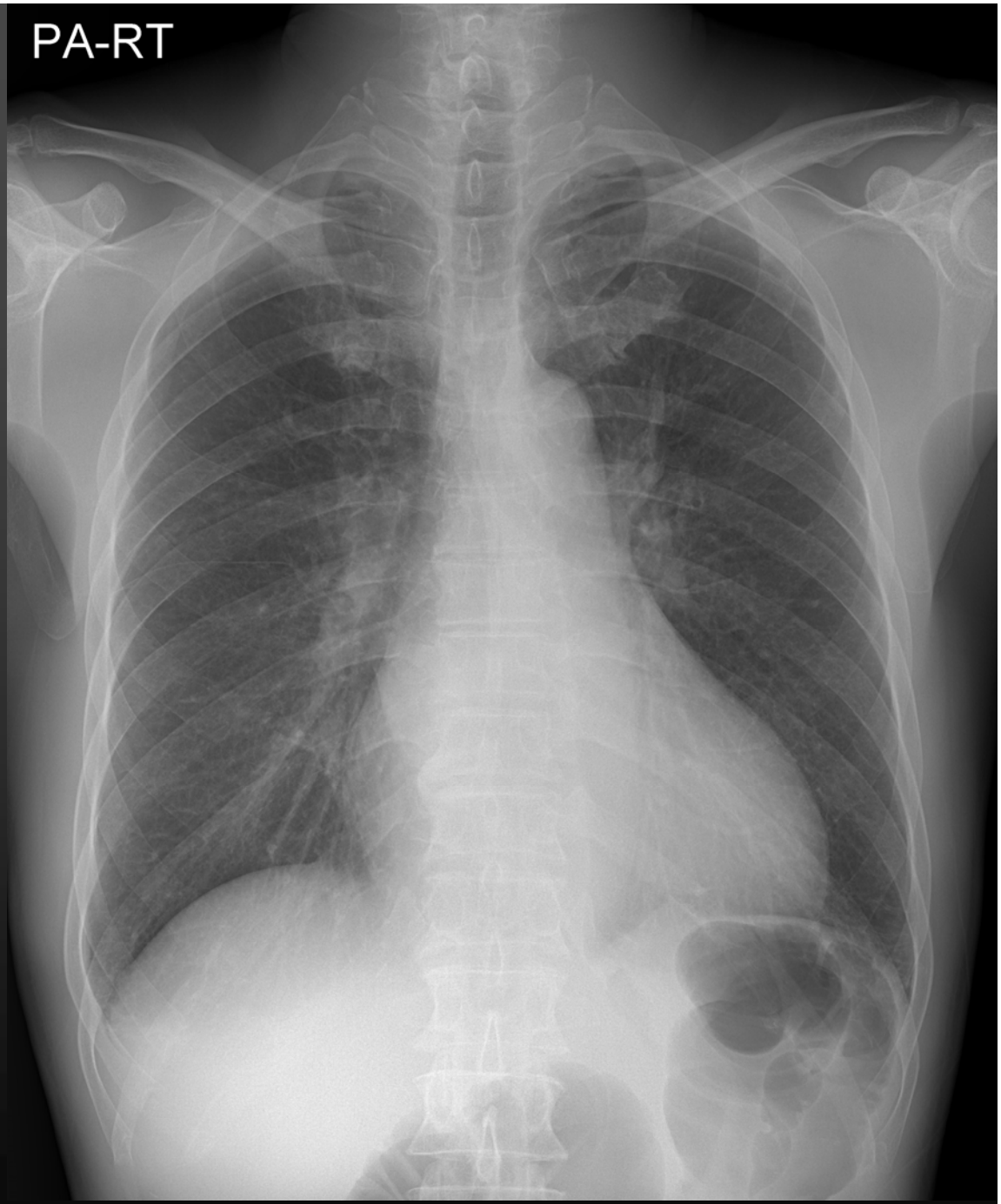
M/73

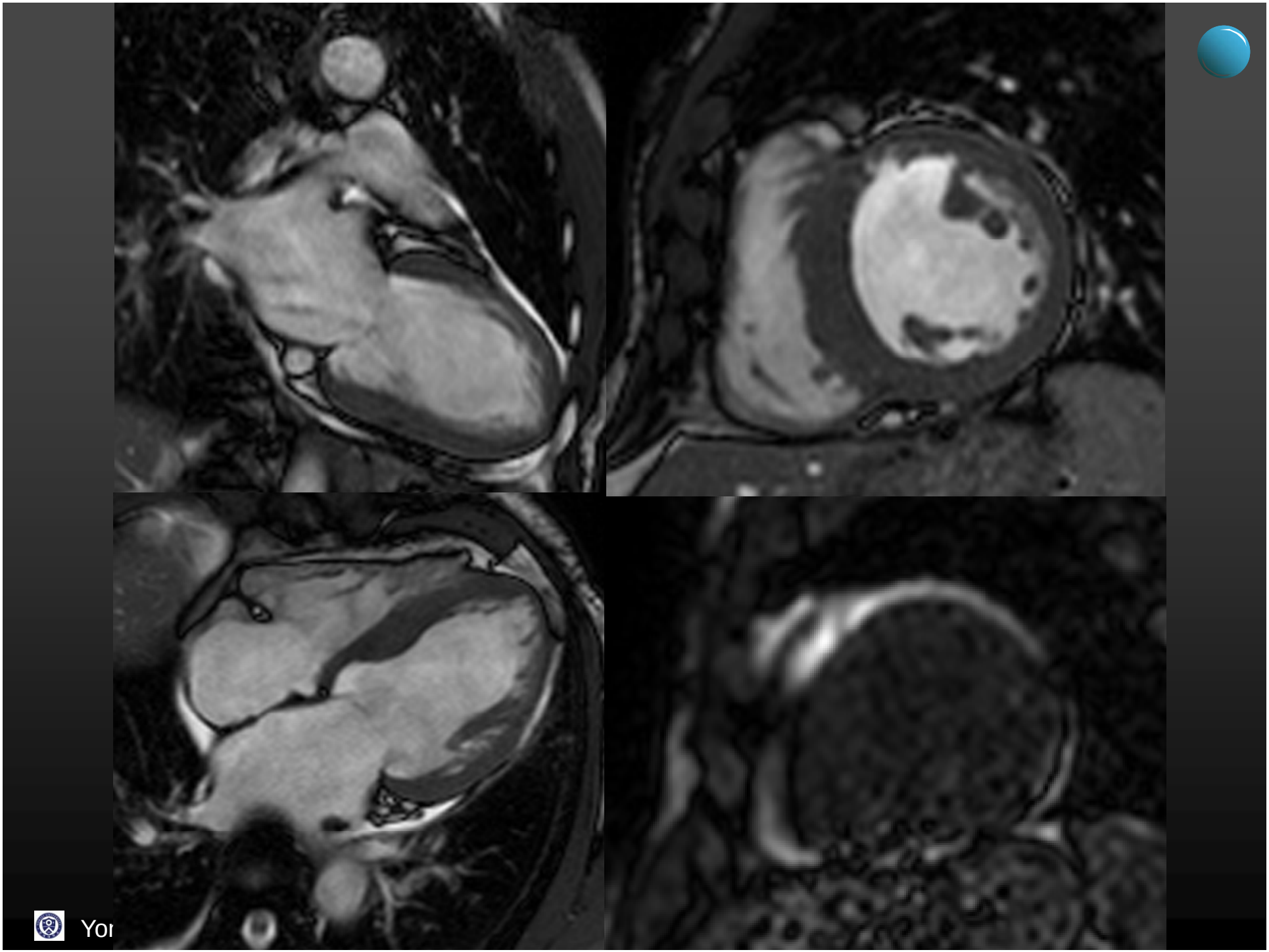
.검진상 우연히 발견된 RLQ mass 수술예정

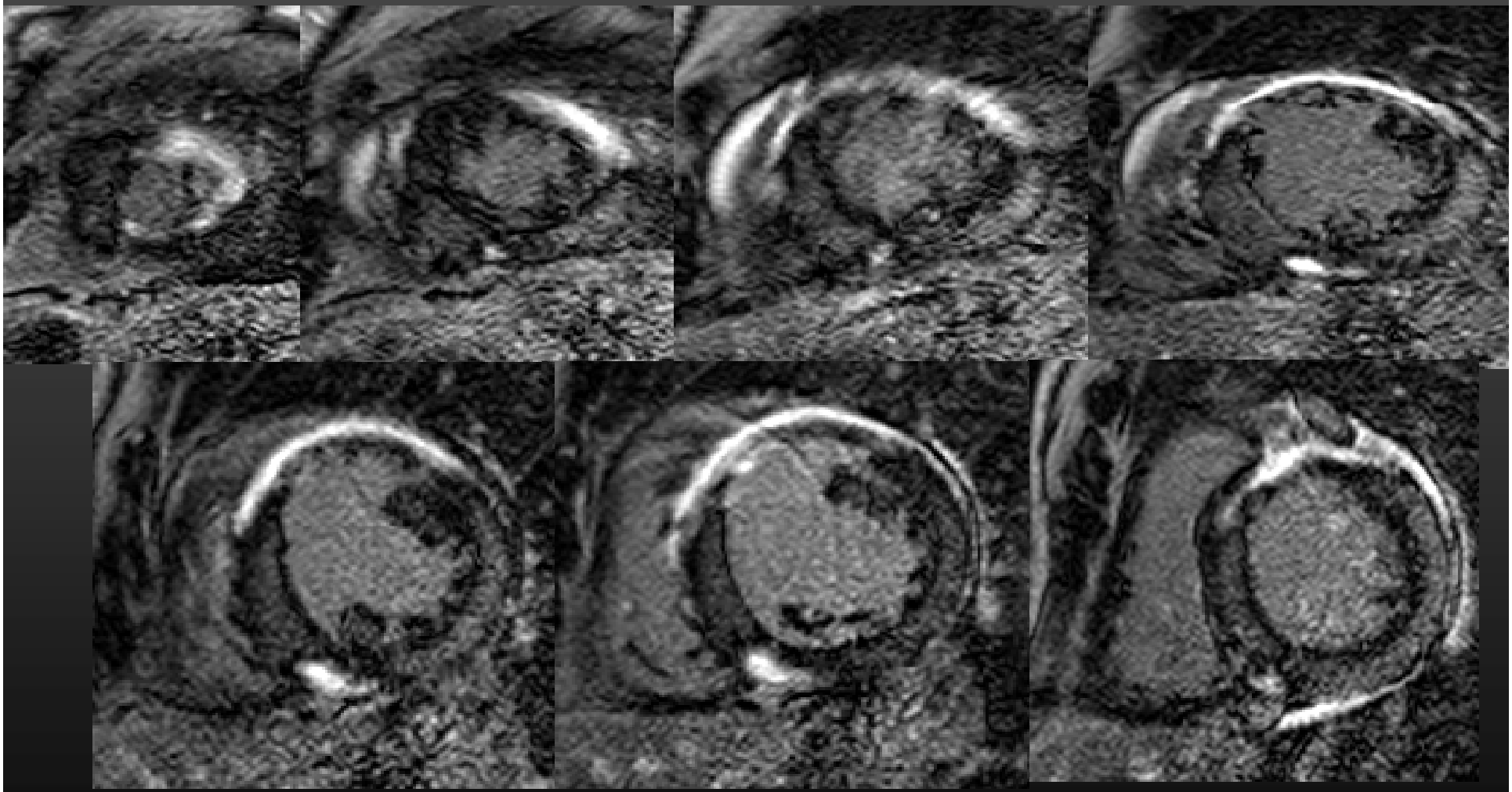
.EKG abnormality and Hypertension;

.Echocardiography:

- Enlarged LA chamber with reduced LV global systolic function (EF=34%)
- LV hypertrophy





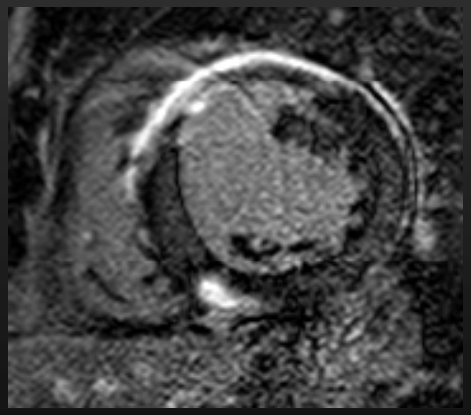


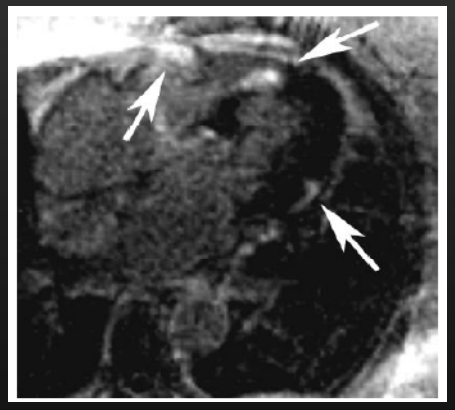
Pathologic diagnosis

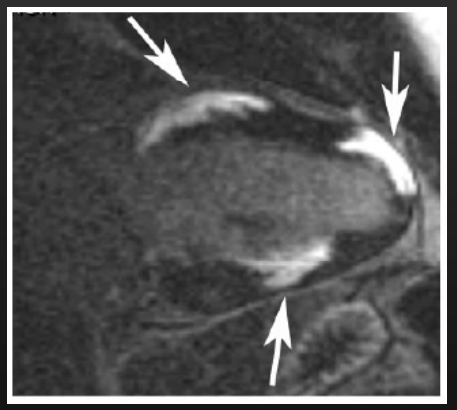
- Heart Biopsy
  - Interstitial fibrosis, moderate.
  - Myocyte hypertrophy, mild
  - Endocardial fibrosis

MRI features of Sarcoidosis

- Delayed enhancement on MRI
  - Multifocal patchy, focal or nodular
  - Location: mid-wall or epicardial
  - DDx: myocarditis.







AJR 2005;184:249–254

RadioGraphics 2006; 26:795–810

M/66

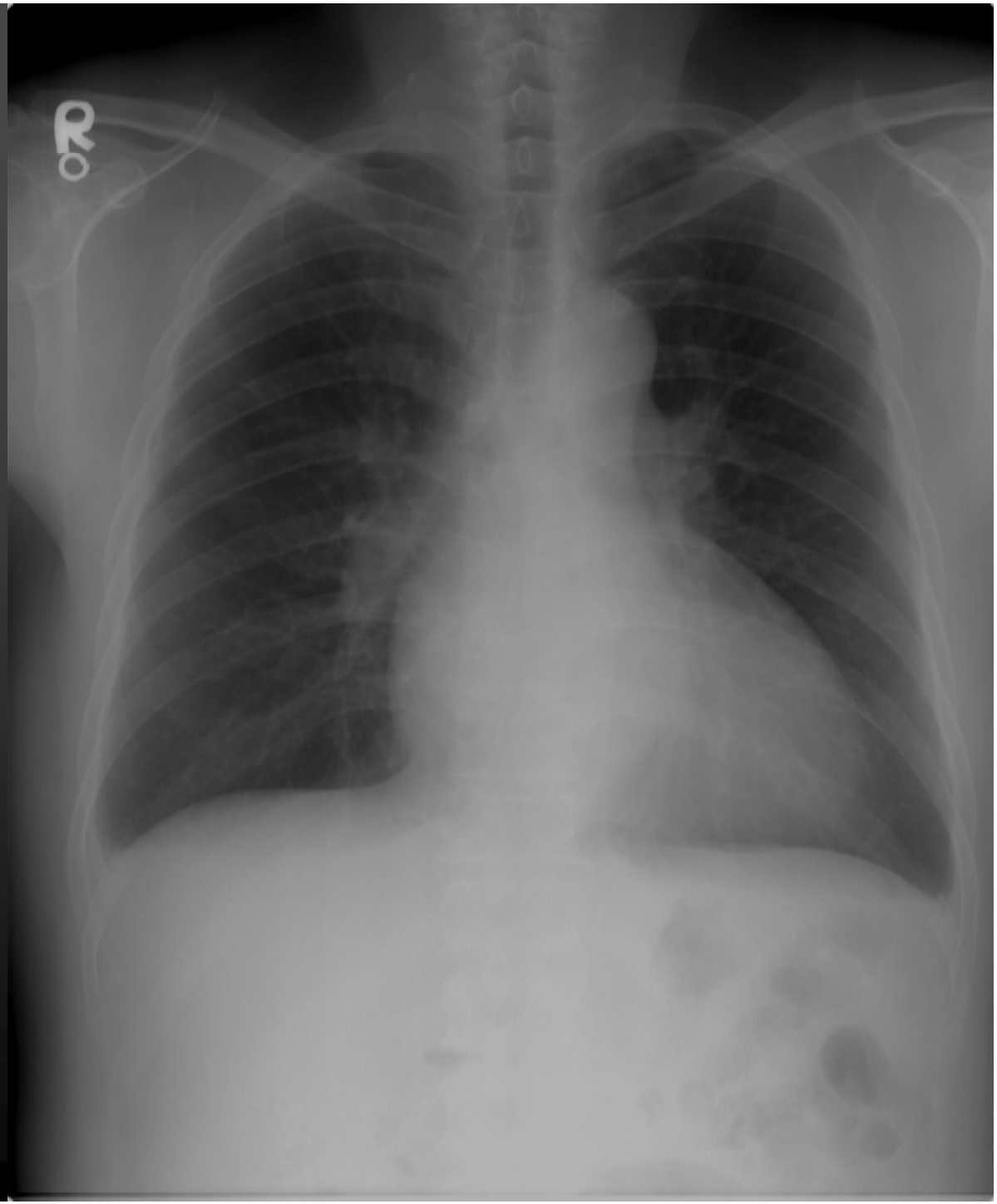
- Chest pain (2 months)
- Hx: Hypertension (3 years)

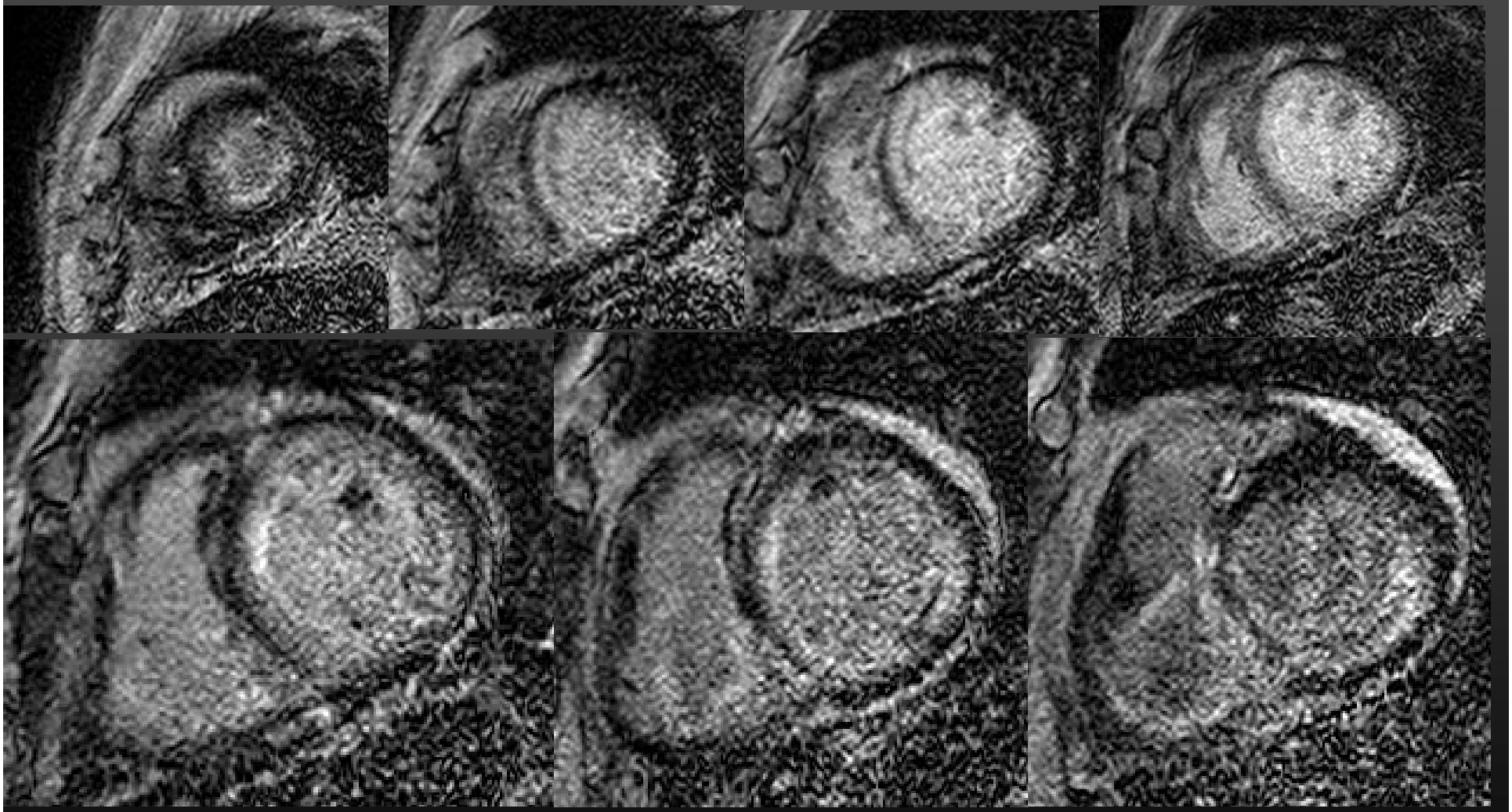
- Echocardiography

-R/O RCMP,

-Enlarged LA chamber with reduced EF=42%

-TR II~III, MR I



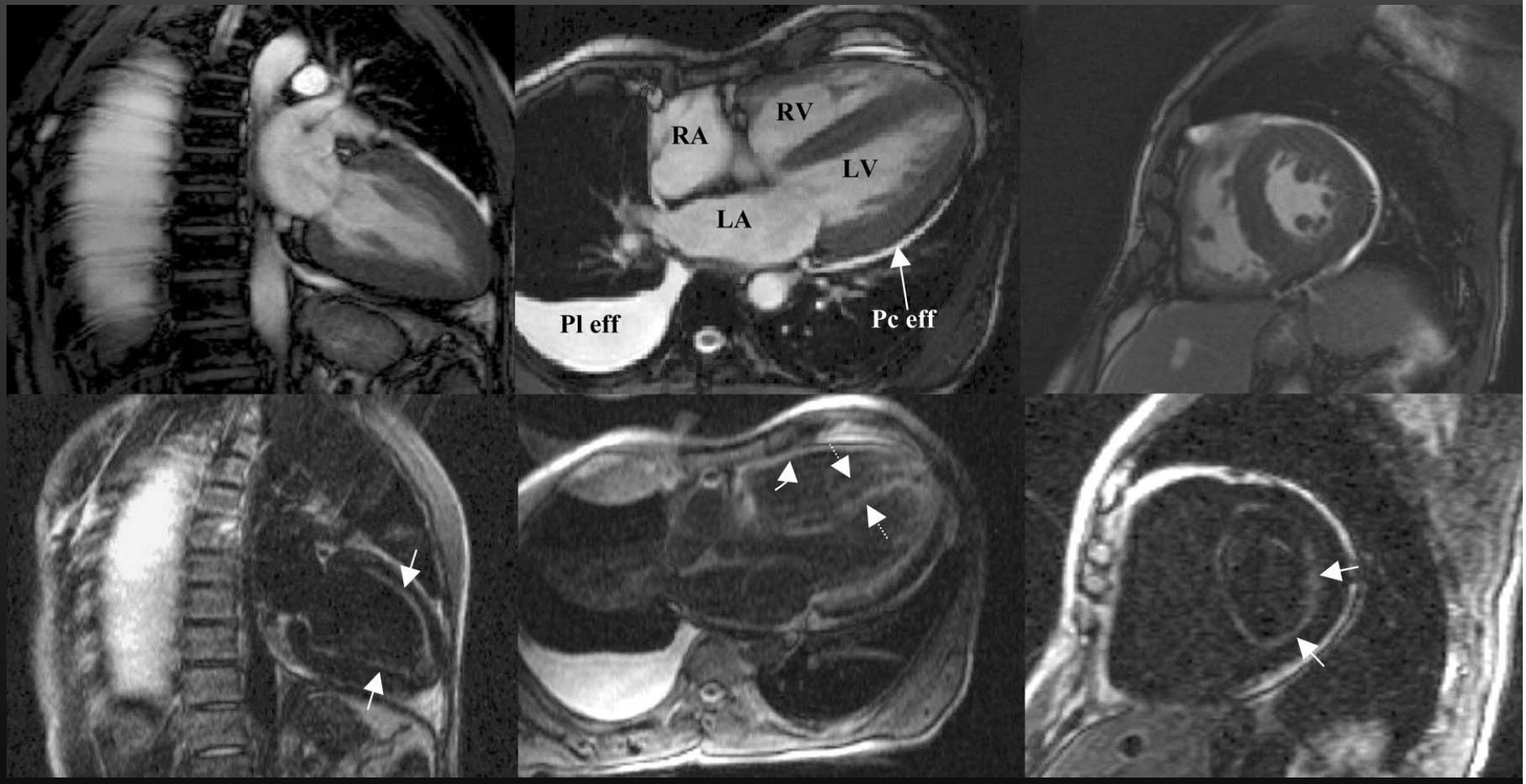


Pathologic Diagnosis

- **Bone marrow biopsy**
  - Primary amyloidosis associated with smoldering or indolent multiple myeloma

Cardiac Amyloidosis

- Global subendocardial hyperenhancement (69%)



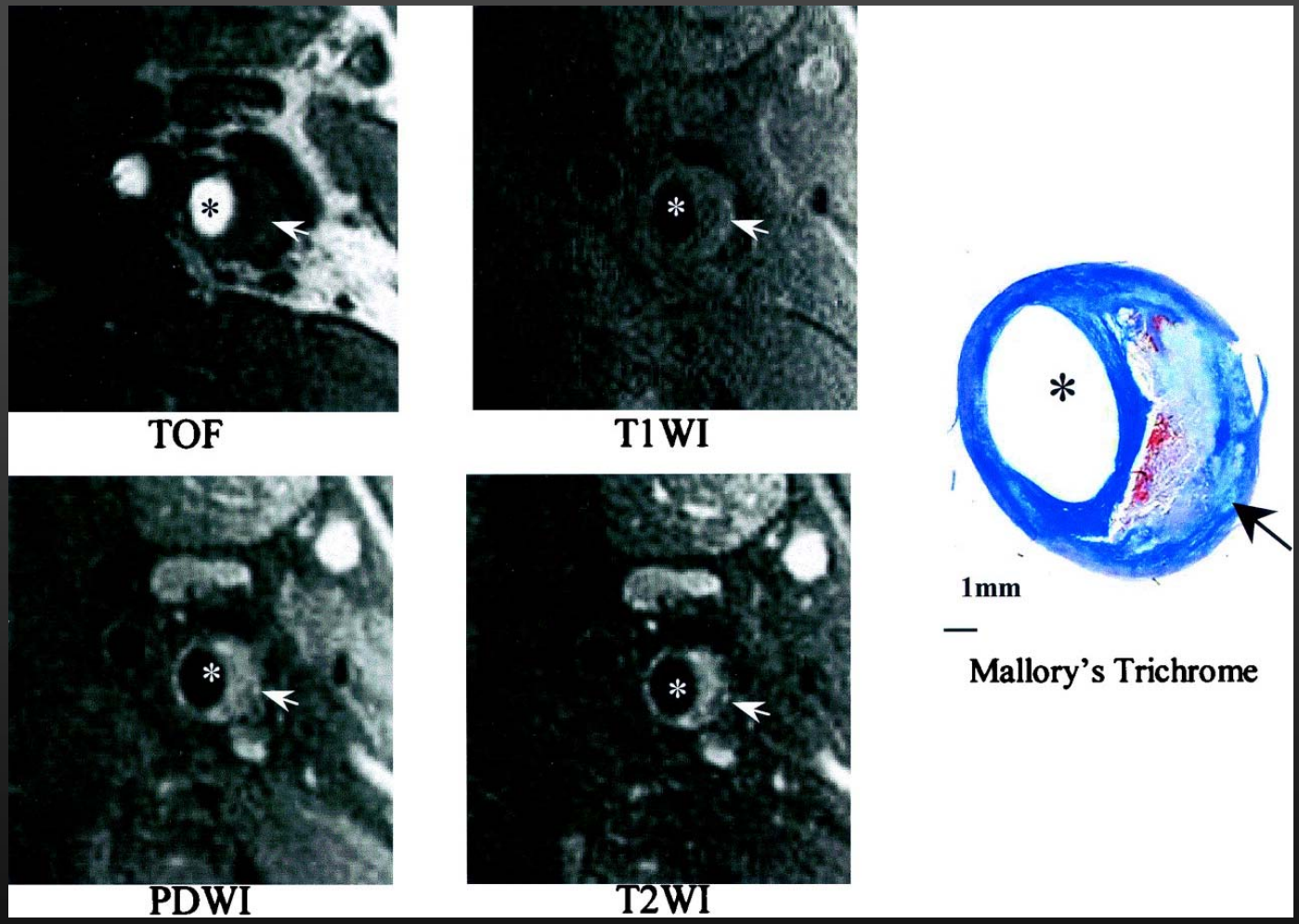
Maceria et al. Circ 2005

Table 1. *Delayed Contrast Enhancement Distribution Patterns in Various Cardiac Pathology*

Condition	Hyperenhancement Pattern	Additional Findings on CMR
Ischaemic cardiomyopathy	"Ischaemic pattern"—subendocardial with variable transmural extension in the territory of coronary arteries	LV thrombus, aneurysms, mitral regurgitation
Dilated cardiomyopathy	Patchy or linear midwall striae without definite coronary artery distribution in ~ 30% of cases	LV thrombus, mitral regurgitation
Hypertrophic cardiomyopathy	Patchy midwall in regions of hypertrophy; RV septal insertion points	Dynamic LV outflow obstruction, mitral regurgitation
Anderson-Fabry disease	Patchy basal infero-lateral wall in 50% of cases	Hypertrophy and dynamic LV outflow obstruction
Arrhythmogenic RV cardiomyopathy	Midwall in areas of fatty replacement/akinesis/aneurysms	RV dilatation/aneurysms/fatty replacement
Amyloidosis	Global subendocardial	Bi-atrial enlargement, pleural effusion, dilated venae cavae, thick LV/RV/atrial walls
Cardiac sarcoidosis	Patchy midwall	Myocardial oedema visualised with T2 weighted sequences in acute sarcoidosis
Myocarditis	Midwall or epicardial (lateral and septal regions)	Myocardial oedema visualised with T2 weighted sequences in acute myocarditis, pericardial effusion
Chagas' heart disease	Midwall or epicardial basal infero-lateral and apical	Apical aneurysm, LV thrombus
Pulmonary hypertension	Patchy midwall at RV septal insertion points and interventricular septum	RV dilatation, interventricular septal bowing, tricuspid regurgitation

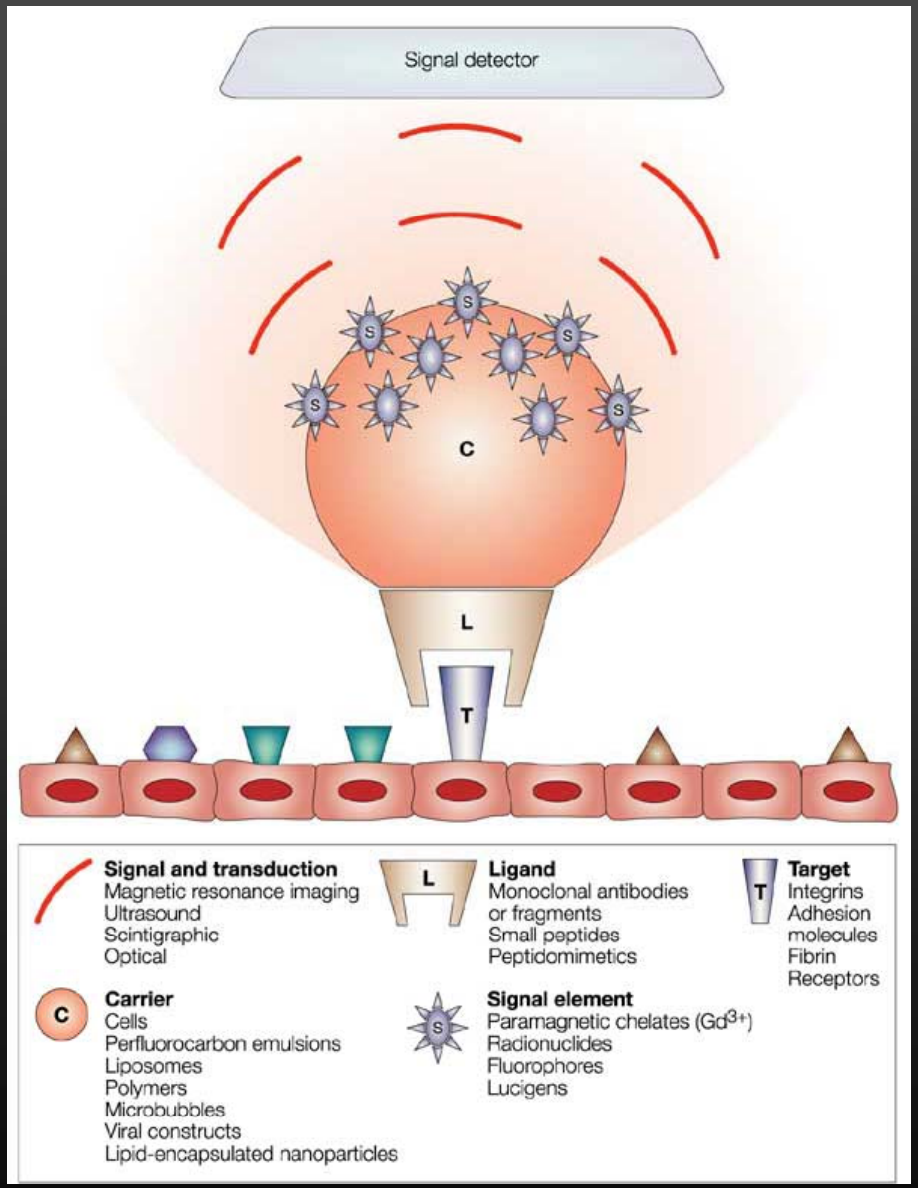
Marcu CB et al. Heart Lung Circ 2007;20:1-9

Example of type IV-V lesion in internal carotid artery (lipid-rich necrotic core was detected by histology)

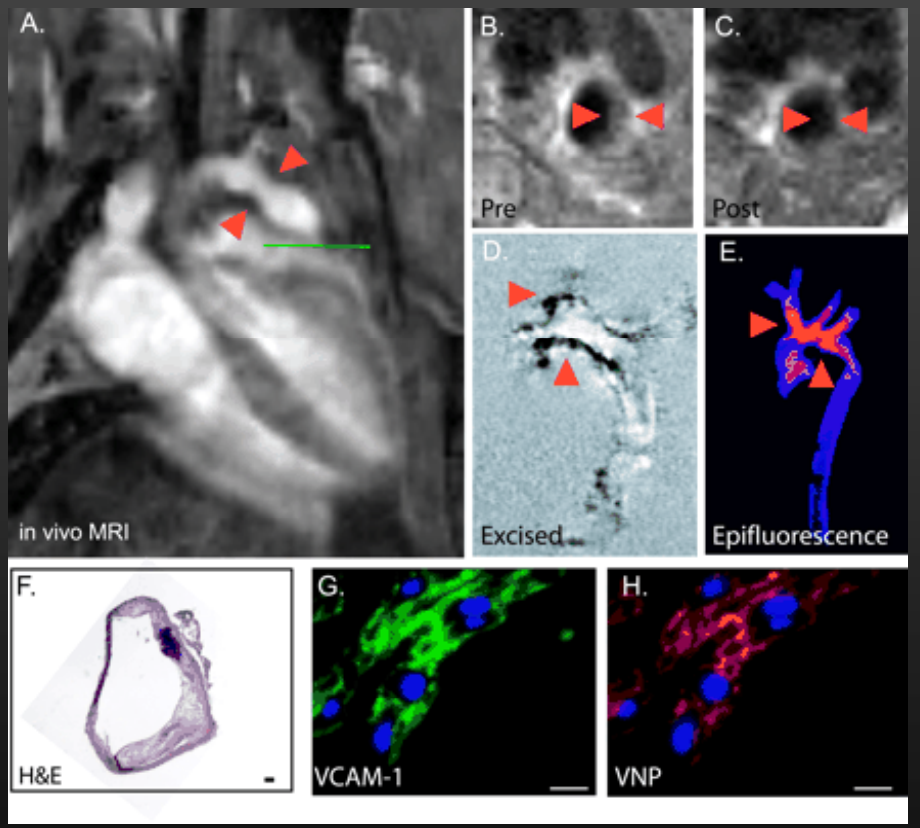


Cai, J.-M. et al. Circulation 2002;106:1368-1373

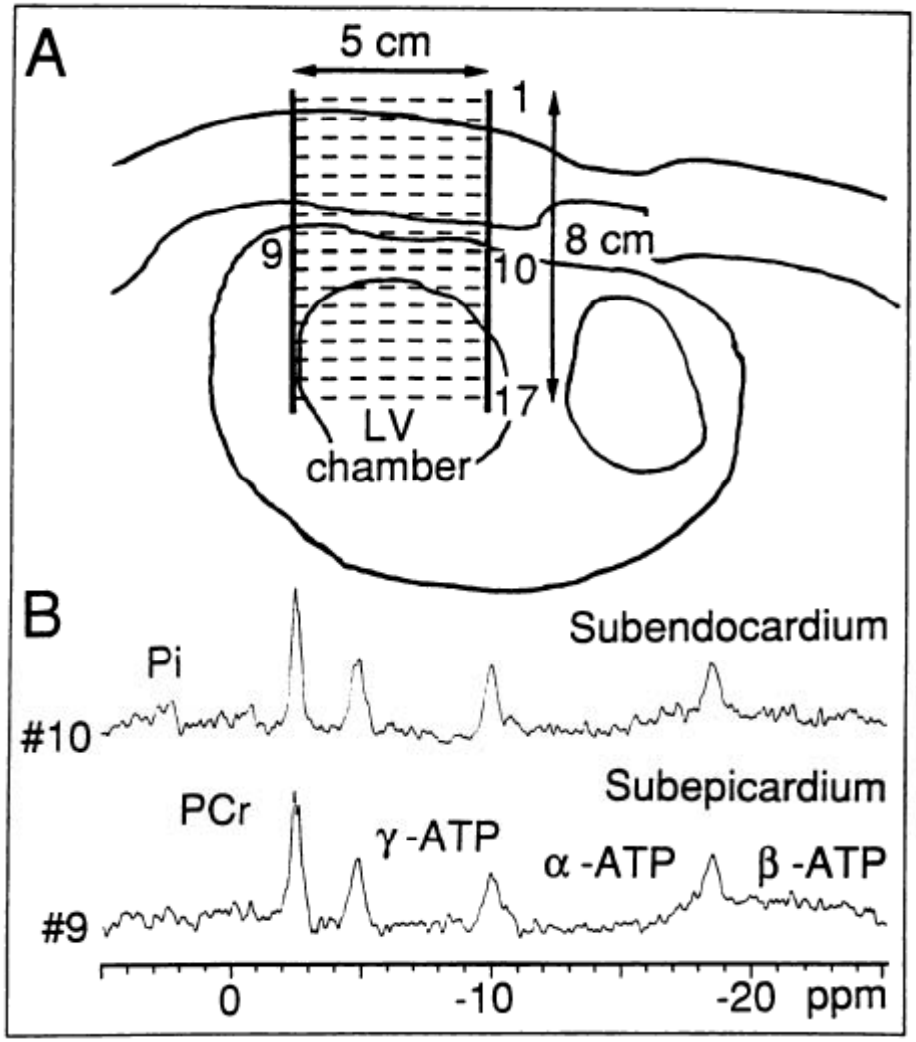
Choudhury et al. Nat Rev Drug Discov 2004;3:913



Novel VCAM-1 peptide affinity ligand from phage display conjugated to magentofluorescent nanoparticle in VCAM-1 expression in murine atherosclerosis



Kelly et al. Circ Res 2005;96:327



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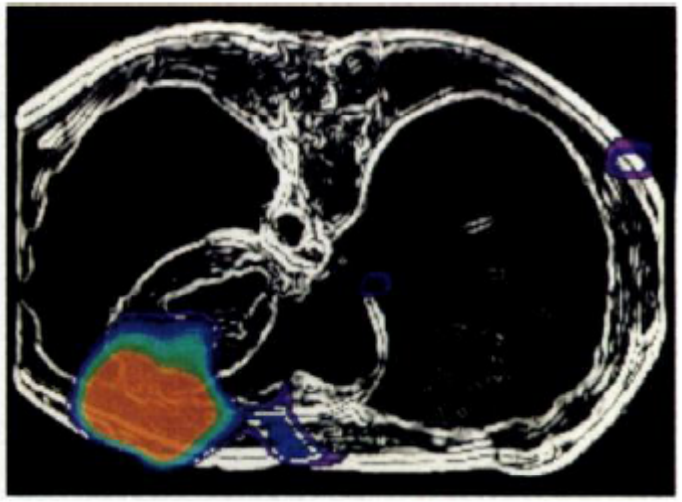

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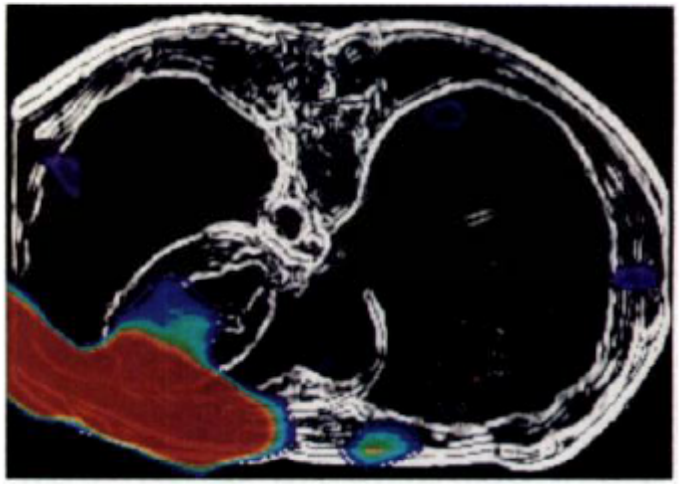

2b.

Figures 1, 2. **(1)** Annotated diagram from an MR image (*A*) shows the location of P-31 MR spectra (*B*) from primarily the subendocardium (location *10*) and from the subepicardium (location *9*) in a healthy volunteer. Data were acquired by Menon et al (*7*) in a 4-T whole-body MR system with a spatial resolution of about 12 mL. (Reprinted, with permission, from reference 7.) **(2)** Color P-31 NMR images of PCr recorded by Hardy et al (20) from **(a)** a single 6.5-cm-diameter surface detection coil and **(b)** a phased array of four overlapping surface coils, superimposed on a corresponding edge-enhanced H-1 image of the human heart. The PCr images were interpolated from a 2 × 2 × 4 cm resolution chemical shift imaging data set obtained in 14–16 minutes at 1.5 T with a separate, uniform P-31 MR excitation coil. The color scale is spectral, with red corresponding to the highest signal, and the relative difference in signal-to-noise ratio between the two coil geometries is preserved. (Re-printed, with permission, from reference 20.)


Thank you !