Future Perspectives of Cardiac MRI

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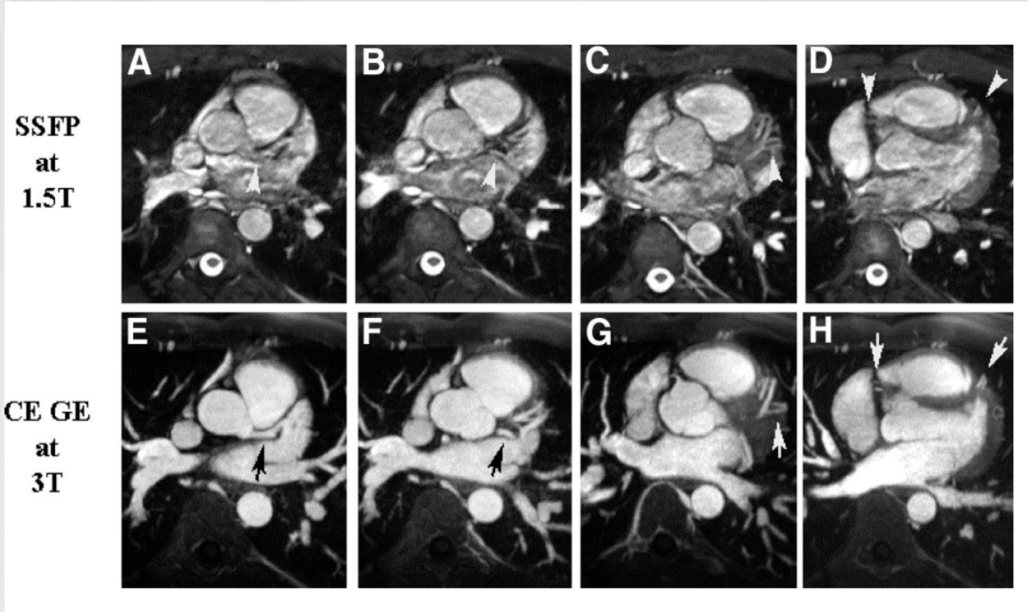
Coronary MRI

- Advantages
  - No radiation
  - No iodinated contrast media
  - “Established” perfusion and viability
- Disadvantages (technical challenges)
  - Motion
  - Scanning times
  - Spatial resolution

Increased resolution using 3-T and contrast media using

- High-field MR imaging
  - 3-T MRI has higher CNR than 1.5-T MRI



Segments	$CNR_{COR\text{-}MYO}$ 1.5 T (SSFP)	3 T (CE FLASH)	*P*
LMS	29.6 ± 18.9	43.5 ± 20.8	0.05
LAD_{prox}	28.6 ± 17.1	45.0 ± 24.6	0.01
LCX_{prox}	23.5 ± 16.1	36.6 ± 21.5	0.05
RCA_{prox}	23.5 ± 18.7	30.4 ± 19.6	0.22
Overall	26.3 ± 15.4	38.9 ± 19.6	0.03

Prompona et al. Invest Radiol 2009;44:369-374

Decrease artifact: respiratory motion correction

Table 1
Quantitative comparison between the three techniques.

Parameter	No respiratory gating with proposed motion correction (MC)	No respiratory gating with no motion correction (noMC)	Navigator gating and slice tracking with ± 3mm acceptance window (NGS)	*P* value (*n* = 9)		
				MC versus NGS	NGS versus noMC	noMC versus MC
Imaging time (min)	6.8 ± 0.9	6.8 ± 0.9	16.2 ± 2.8	<**0.001**	<**0.001**	–
Navigator efficiency (%)	100.0 ± 0.0	100.0 ± 0.0	43.44 ± 11.5	–	–	–
Image quality score	3.25 ± 0.32	1.87 ± 0.46	3.36 ± 0.40	0.084	<**0.001**	<**0.001**
RCA sharpness (mm^{-1})	0.84 ± 0.07	0.68 ± 0.13	0.81 ± 0.10	0.238	**0.003**	**0.002**
RCA diameter (mm)	3.31 ± 0.46	3.61 ± 0.60	3.36 ± 0.39	0.703	0.157	0.201
RCA length (cm)	11.63 ± 2.18	9.08 ± 2.84	12.11 ± 1.82	0.256	**0.004**	<**0.001**
LAD sharpness (mm^{-1})	0.83 ± 0.09	0.61 ± 0.07	0.84 ± 0.12	0.677	**0.001**	**0.001**
LAD diameter (mm)	3.23 ± 0.74	3.54 ± 0.95	3.28 ± 0.76	0.782	0.355	0.344
LAD length (cm)	9.16 ± 1.17	5.46 ± 2.57	9.13 ± 1.12	0.908	**0.006**	**0.003**
LCX sharpness (mm^{-1})	0.92 ± 0.06	0.65 ± 0.14	0.90 ± 0.08	0.667	**0.031**	**0.009**
LCX diameter (mm)	2.80 ± 0.49	3.28 ± 0.19	2.90 ± 0.44	0.338	0.051	0.050
LCX length (cm)	6.32 ± 1.31	2.07 ± 1.57	6.13 ± 1.10	0.372	**0.001**	**0.002**

Figure 1 Reformatted image without correction (left), with navigator binning (middle), and with SEGMO (right).

Bhat et al. MRM 2011;65:1269
Pang et al. SCMR 2012

Optimization of parameters using high field MR

- ↓ Acquisition window is more effective than ↑ spatial resolution.
- Double oblique whole-heart MRA is better.
- 3T: smaller voxel size than 1.5T

Gharib et al. MRI 2011;29:1125-1130

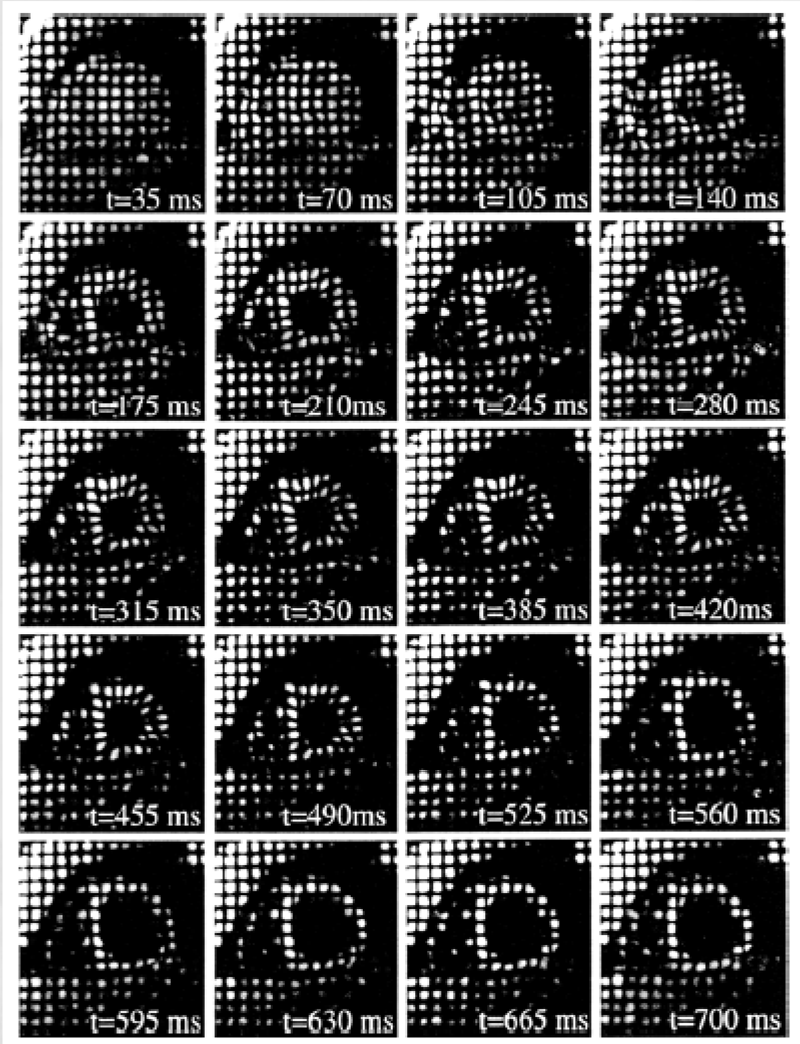
Regional wall motion abnormalities

- **Myocardial tagging** segmented k-space spoiled gradient echo pulse sequences with a spatial modulation of the magnetization (SPAMM) and complementary SPAMM (CSPAMM)
  - SPAMM
    - Usually fade in the early diastole (app 400-500 ms)
  - CSPAMM
    - Improved tag persistence
    - Used both systole and diastole
    - Disadvantages
      - double acquisition time and scan time: misregistration

Regional wall motion abnormalities

- Myocardial tagging using EPI CSPAMM
  - Image acquisition

    in one-breath hold



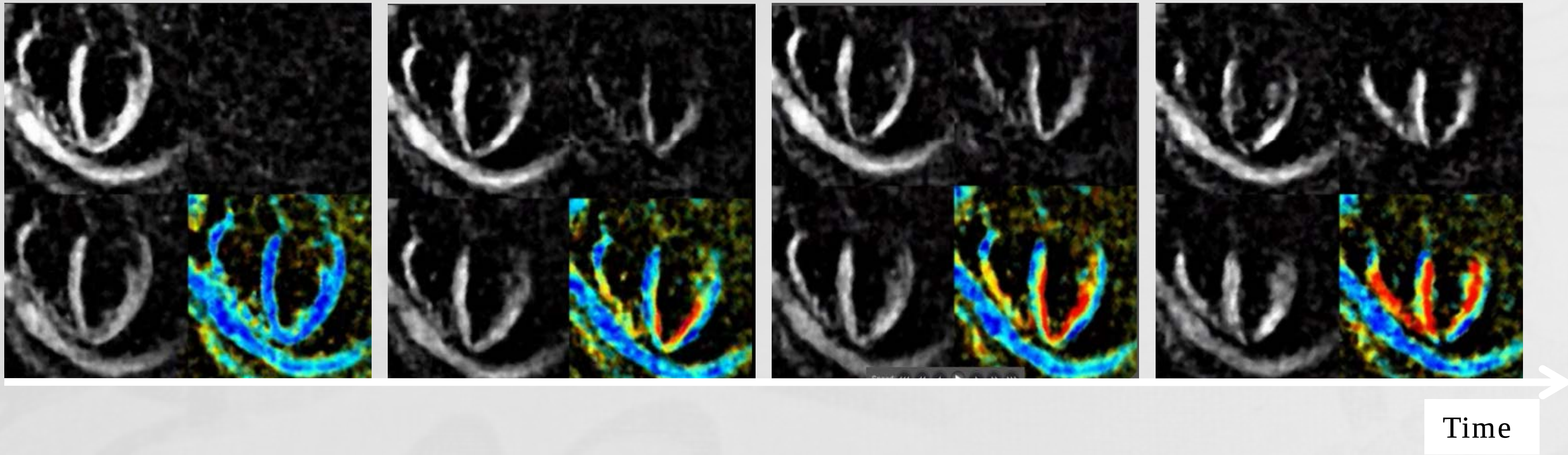
Stuber et al. MAGMA 1999

Regional wall motion abnormalities

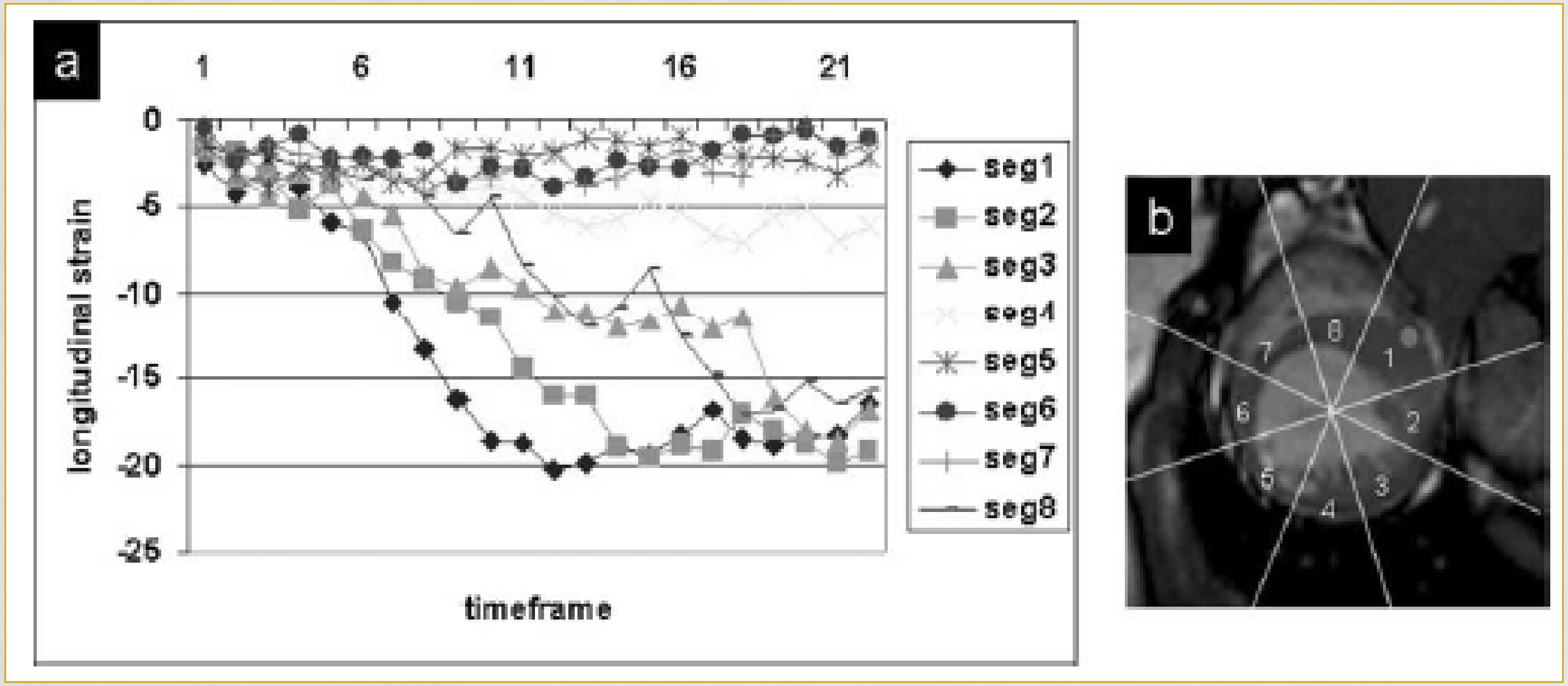
- New approaches
  - Inherent tissue tracking rather than tagging.
    - Harmonic phase imaging (HARP)
    - Strain-encoded (SENC) MR
    - Displacement encoding with simulated echoes (DENSE)
  - Encode tissue displacement (HARP and DENSE)
  - Directly encode strain (SENC)

Regional wall motion abnormalities

- SENC
  - Direct encoding of regional strain of the heart into the acquired image.
  - Measure the strain in the direction orthogonal to the image plane.
  - In case of short-axis images, only the longitudinal compression of the myocardium from base to apex is measured. On the other hand, circumferential shortening of the myocardium can be measured in the long-axis views of the heart (such as the four-chamber view).



Decreased strain of RCA territory with wall thinning



Flow quantification

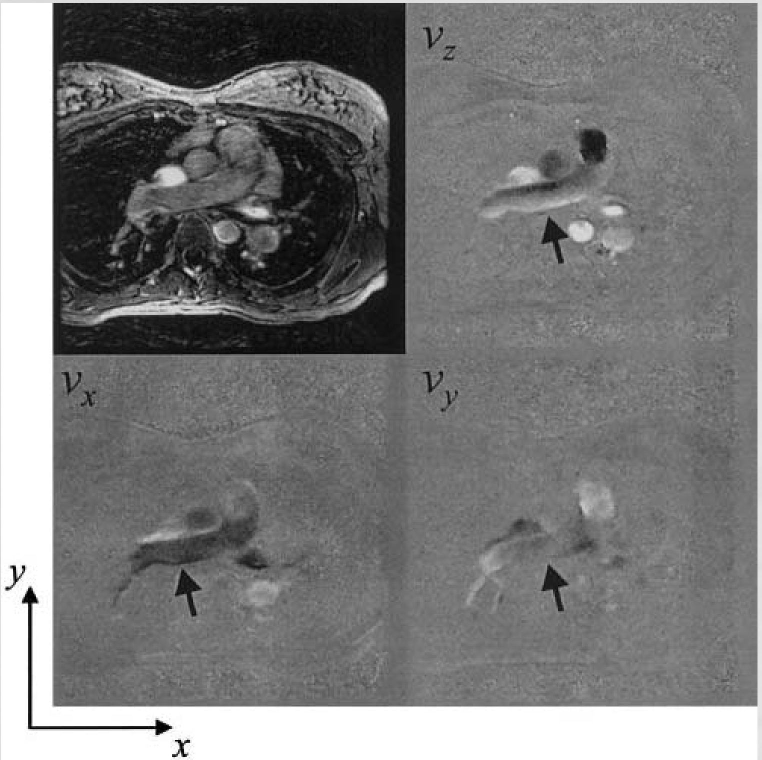
- 2D Velocity encoded cine (VENC) MR
  - Most widely used.
- Newer sequences of VENC MR
  - Resolution of velocity vector in 3D
  - Spatial coverage of 3D volume
  - Temporally resolved throughout cardiac cycle

  → Complete spatial and temporal resolution of velcoity

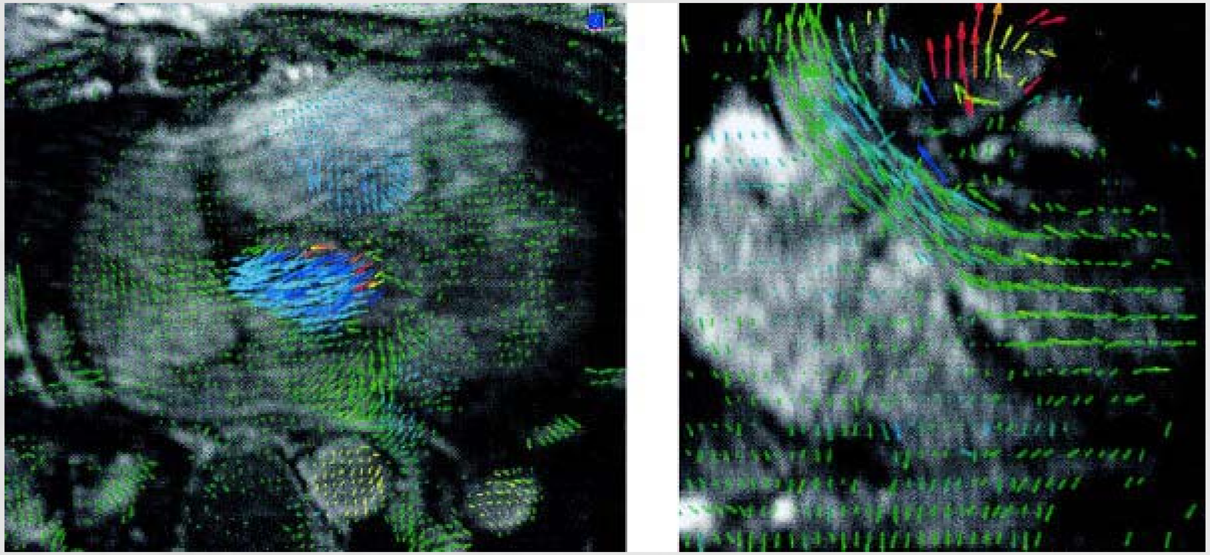
  → Higher SNR

  - Flow patterns of the heart, great vessels.
  - More accurate information of velocity.

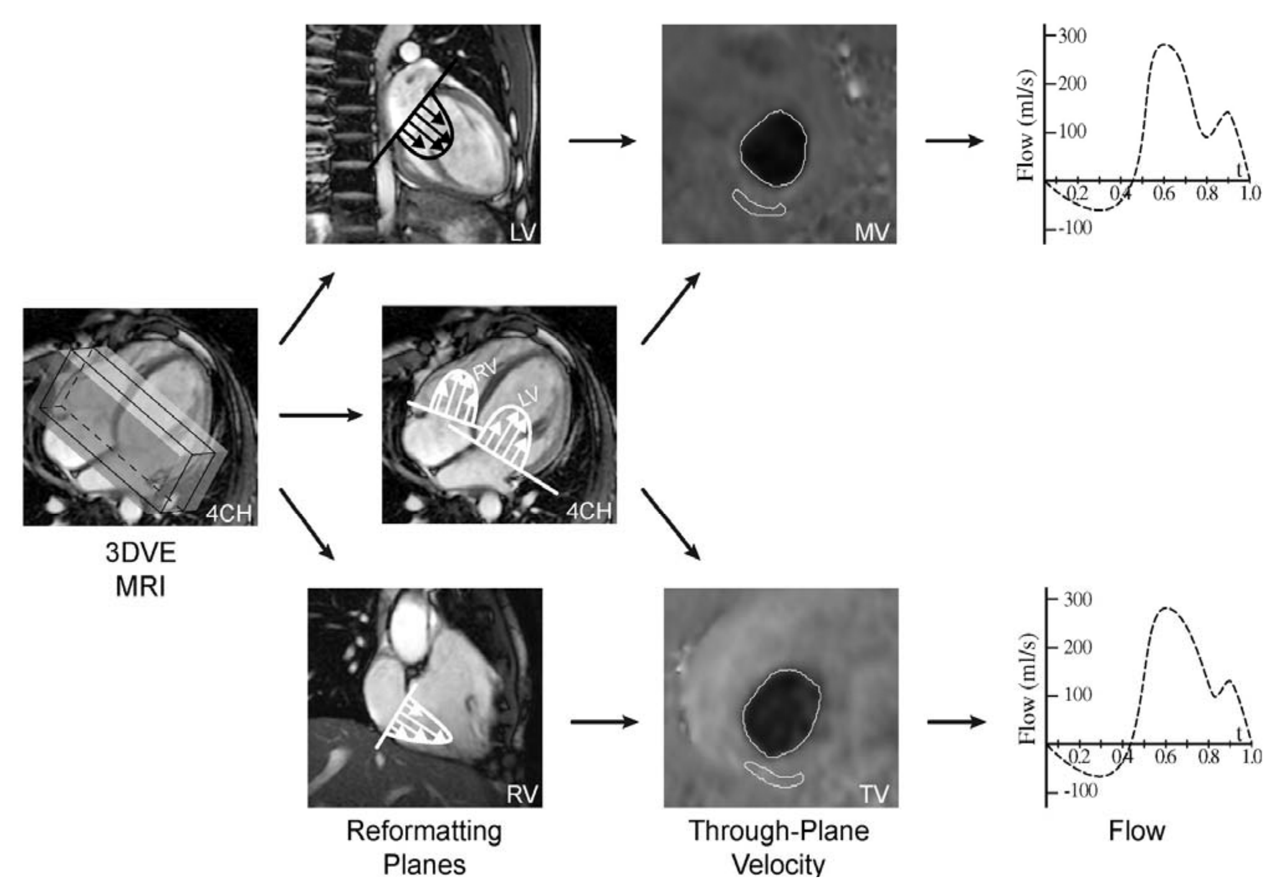
PC images for x-,y-,and z-axis veloci
ty

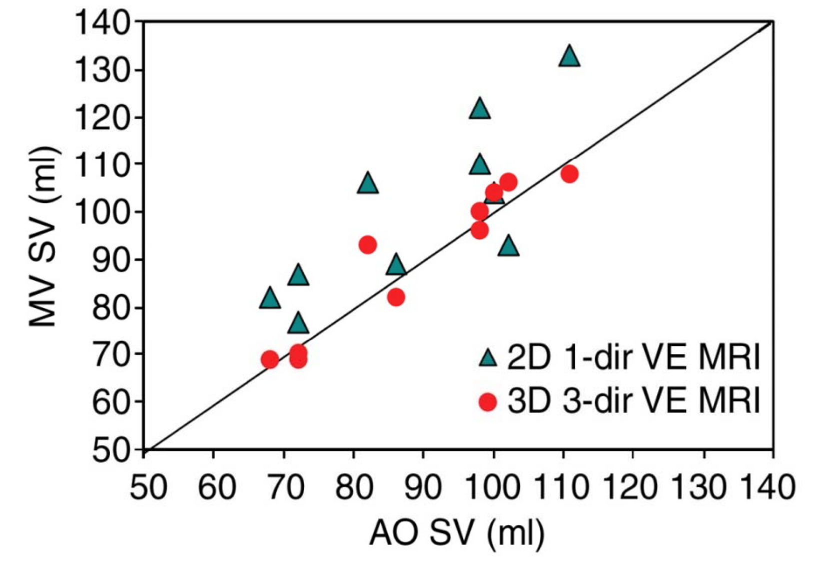


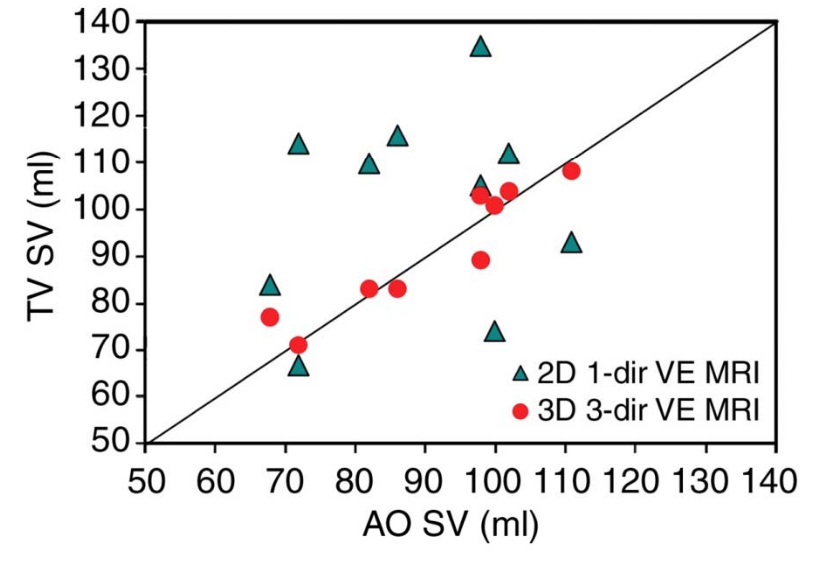
Patterns of aorta flow



Markl et al. JMRI 2003



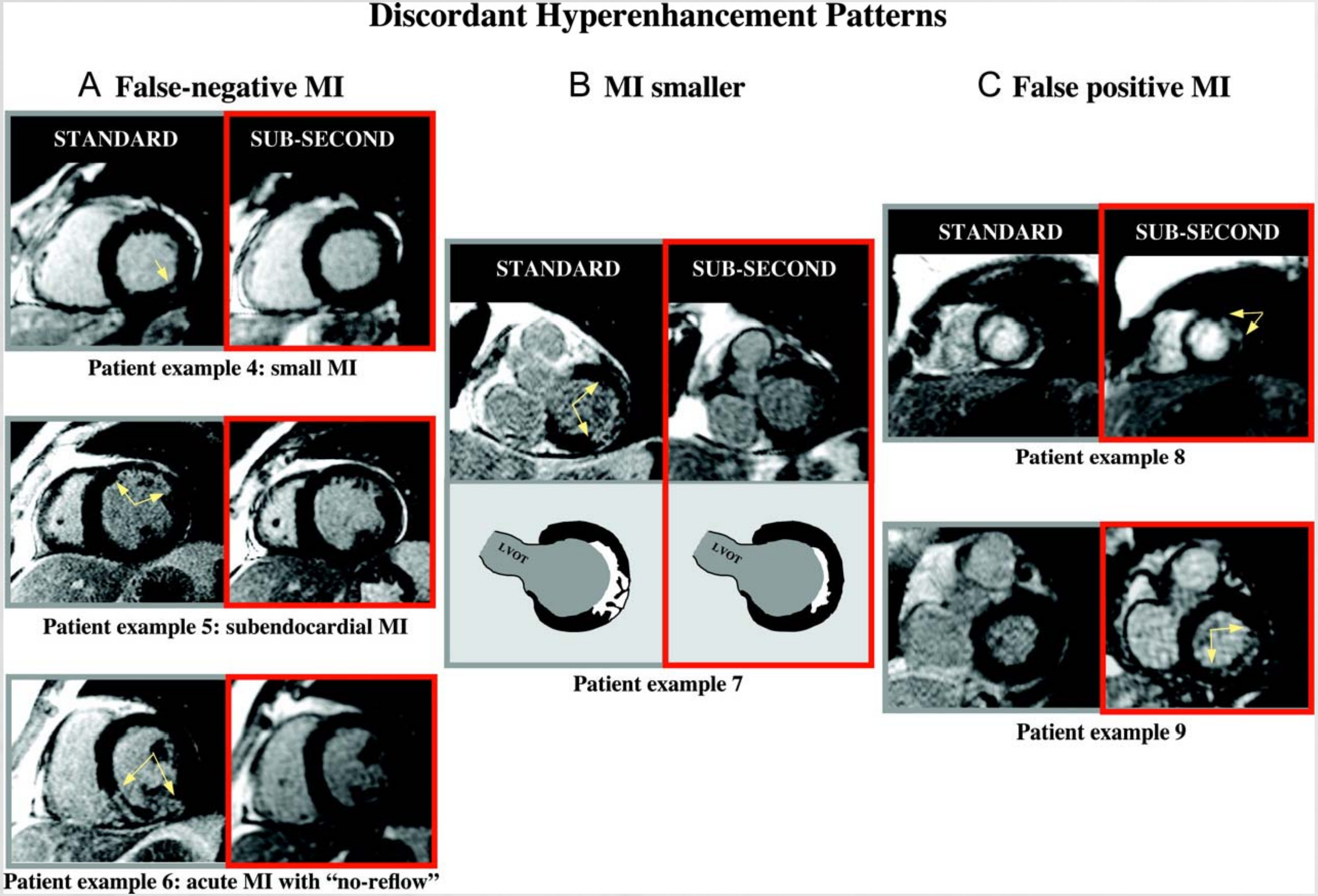




Westenberg et al. Radiology 2008

Myocardial scar (DE-MRI)

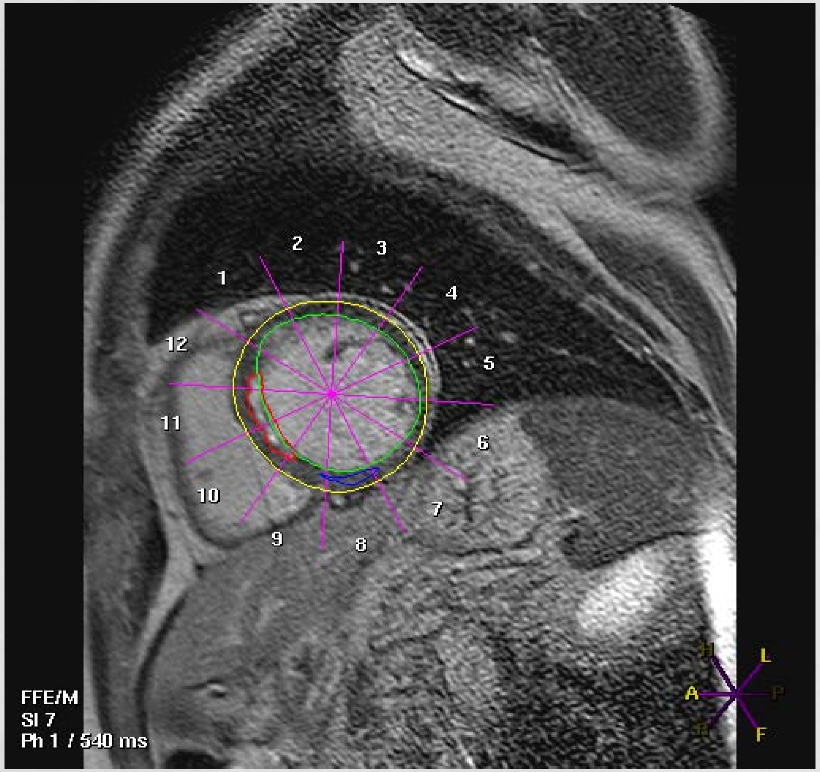
- 2D-IR spoiled gradient echo
- Real-time acquisition without breath hold (IR-SSFP)
  - Advantage : less than 30s scan
    - For acutely ill, cannot hold one's breath
    - Arrhythmia
  - Disadvantage
    - Lower spatial resolution
    - Less T1 weighting
    - Reduced CNR: mildly decreased sensitivity and underestimation of transmural extent

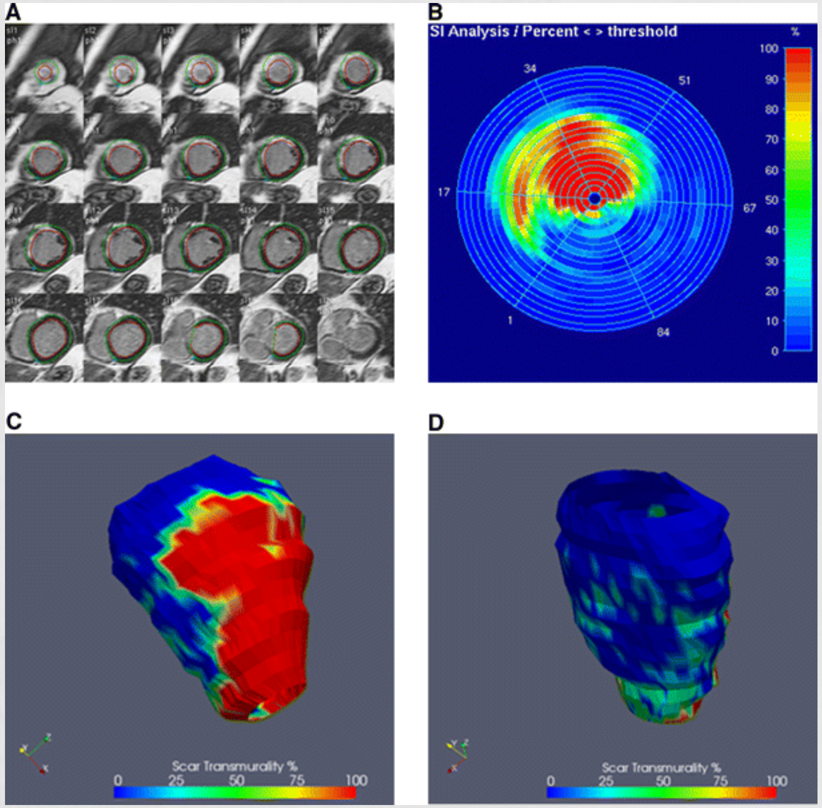


Sievers et al. Circulation 2007

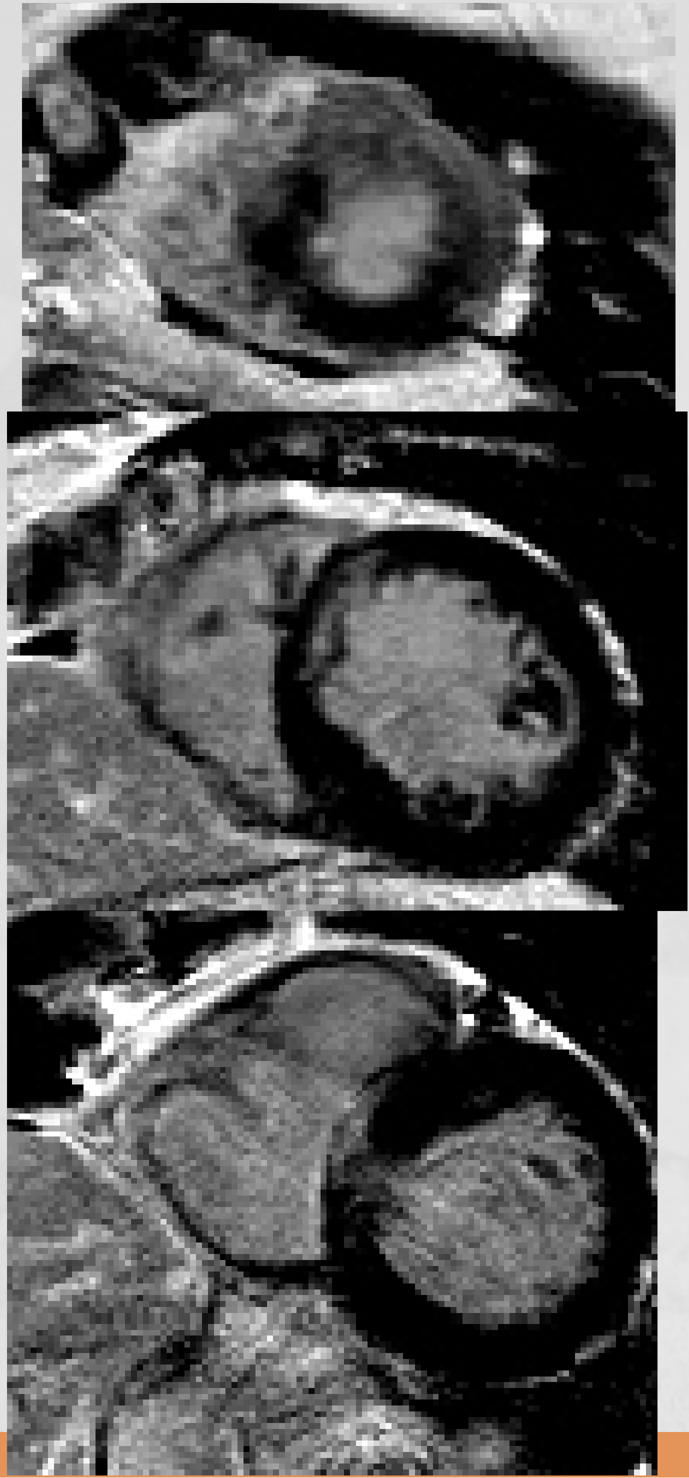
Myocardial scar (DE-MRI)

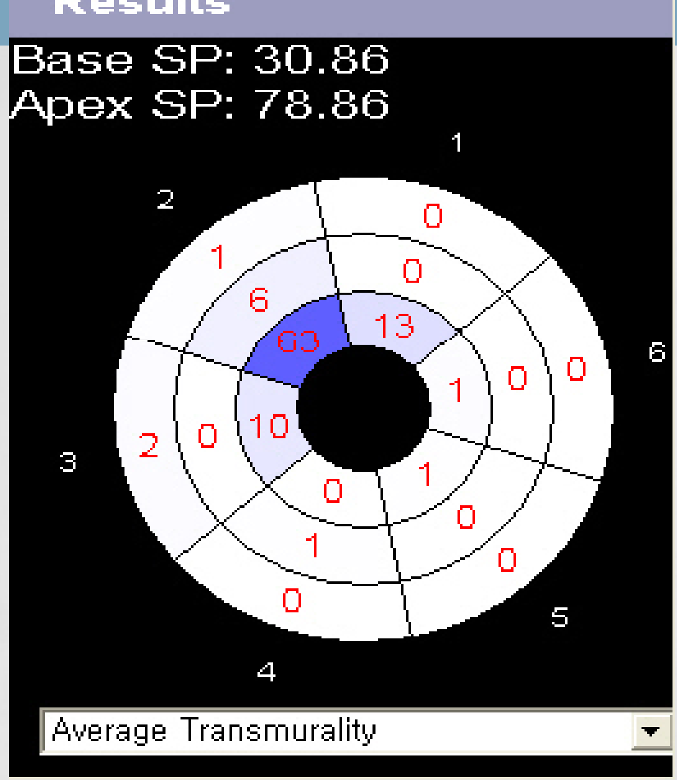
- Quantification of scar
  - Using standard deviation
    - SI more than 2 (m.c) or more st-dev than normal



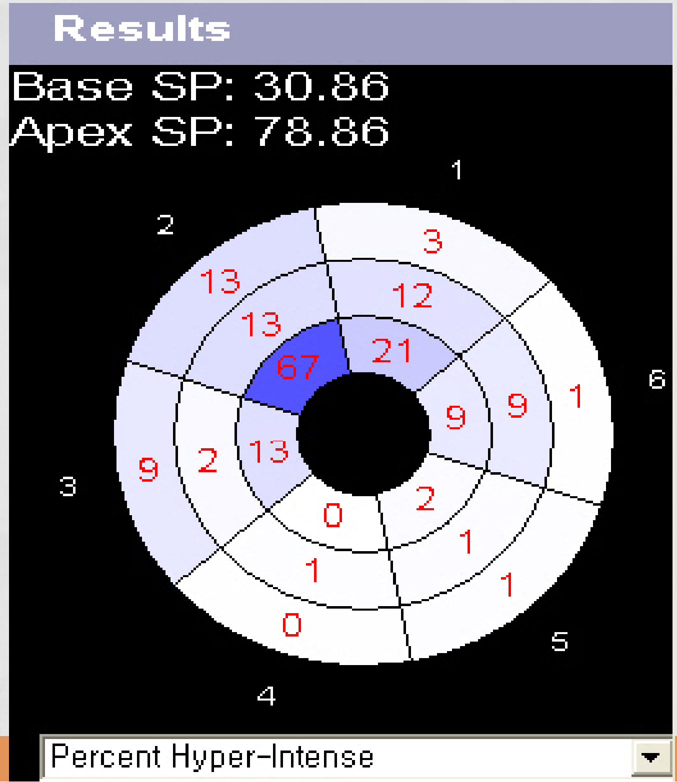


Attili et al. Int J CV Imaging 2010





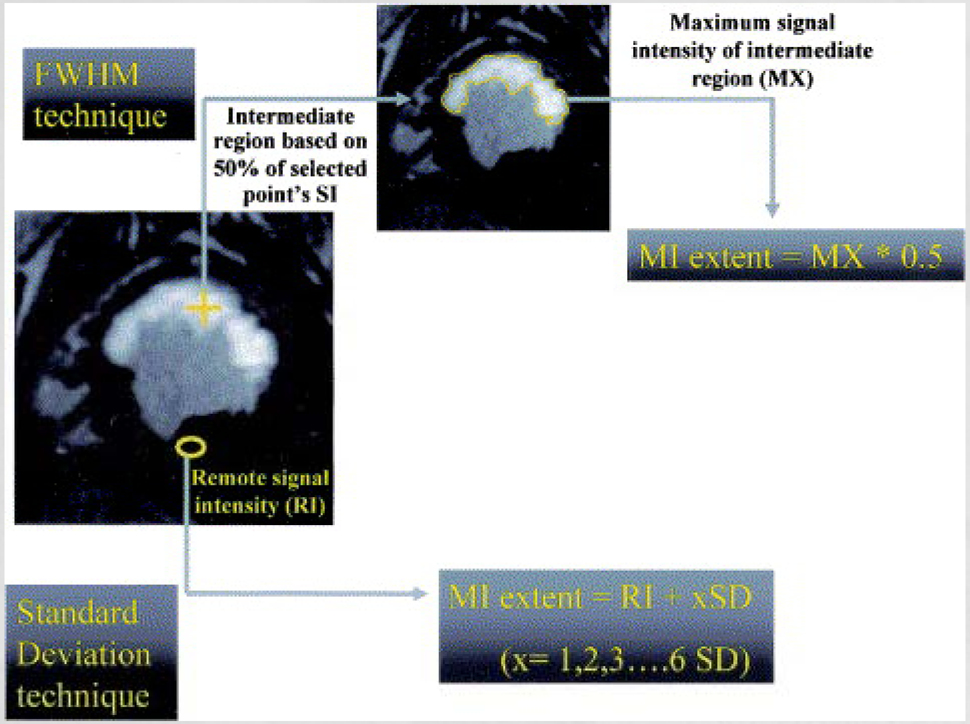
Base SP: 30.86
Apex SP: 78.86
1
2
6
3
4
5
0
0
13
63
6
1
0
0
1
10
0
2
0
1
0
0
1
0
Average Transmurality



Results
Base SP: 30.86
Apex SP: 78.86
1
2
6
3
4
5
3
12
21
67
13
13
1
9
9
13
2
9
0
2
1
1
1
0
Percent Hyper-Intense

Myocardial scar (DE-MRI)

- Quantification of scar
  - Full-width-half-maximum model
    - Much less sensitive to variations in image acquisition parameters

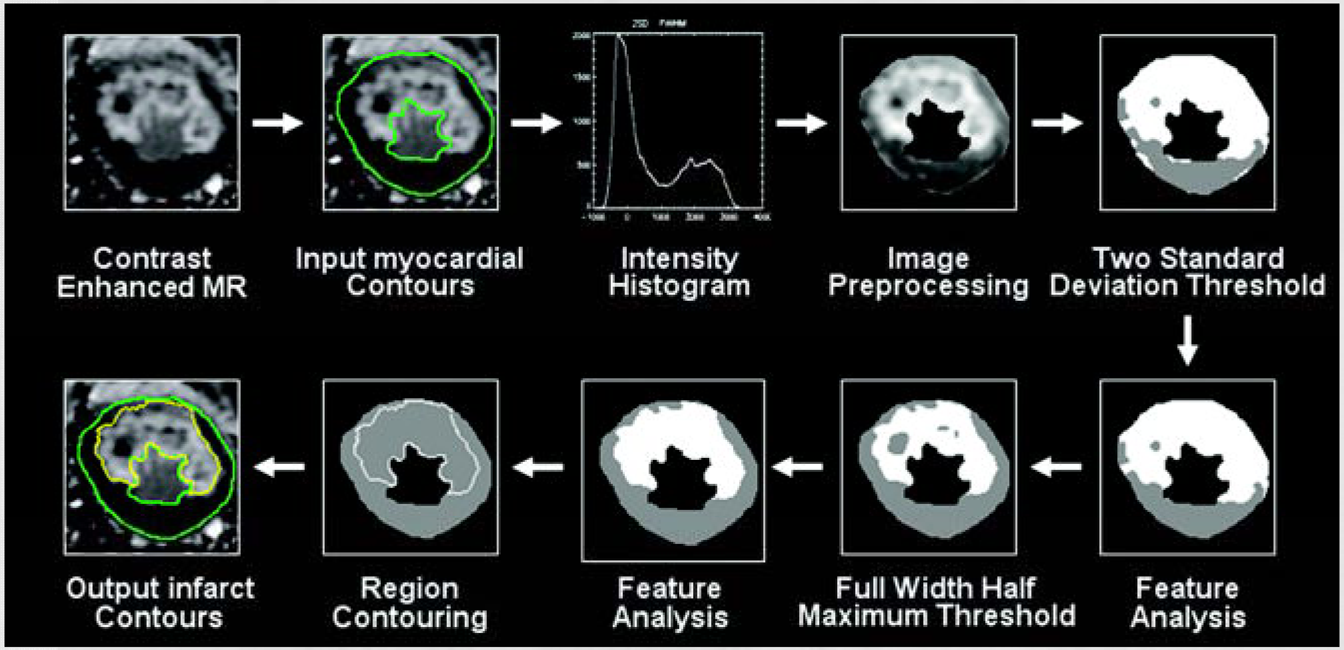


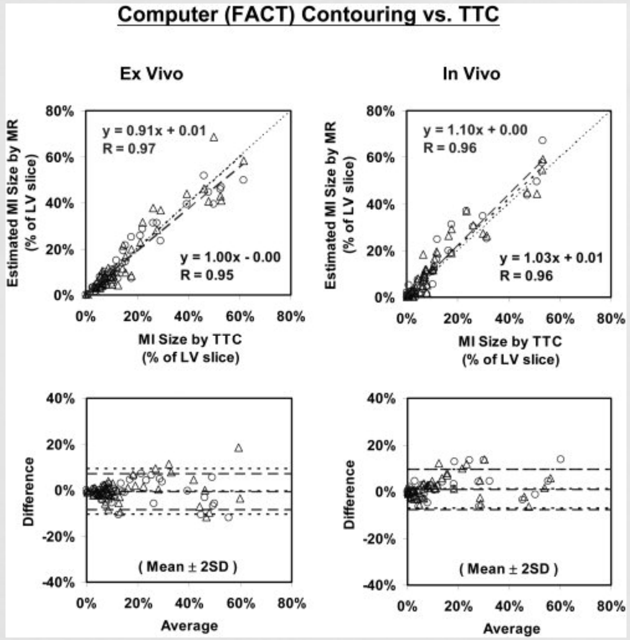
full-width at half-maximum (FWHM) criterion—an initial region is determined to grow to include all pixels with signal intensity (SI) >50% of a user selected point. The maximum signal intensity (MX) inside this initial region is then determined, and the final MI extent is defined as the area presenting with a signal intensity 50% above the maximum of the initial region (MI = MX * 0.5).

Amado et al. JACC 2004

Myocardial scar (DE-MRI)

- Quantification of scar
  - Fully automated technique to obtain accurate assessment of the size of MI.

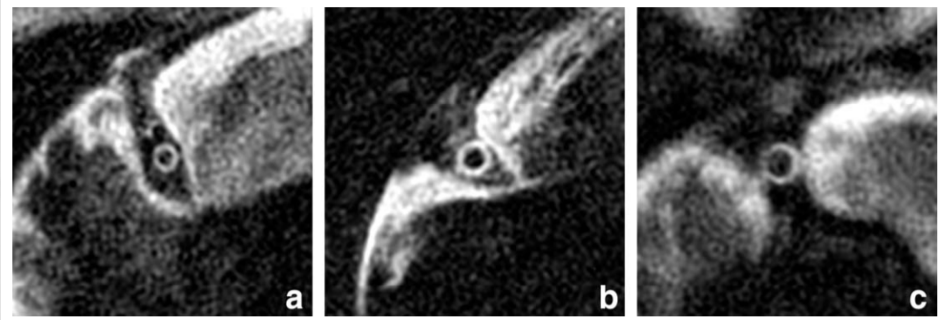




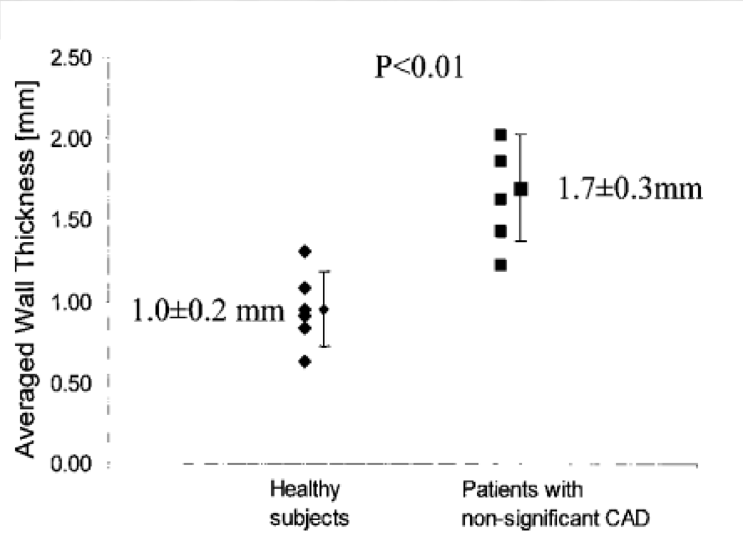
Hsu et al. JMRI 2006

Vessel wall and plaque imaging (I)

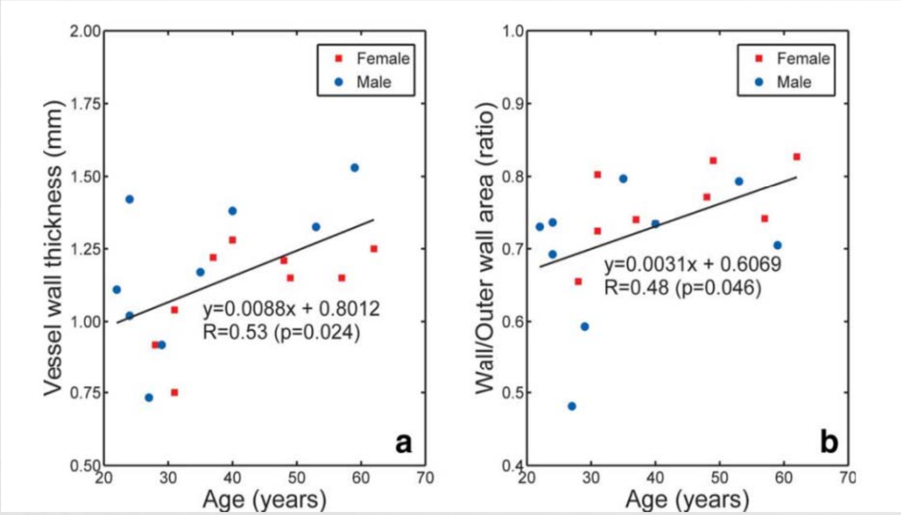
- Vessel wall thickness ↑
  : CAD and aging
- Wall enhancement
- High intensity plaque



24yr *40yr* *59yr*



Kim, WY. et al. Circulation 2002;106:296-299

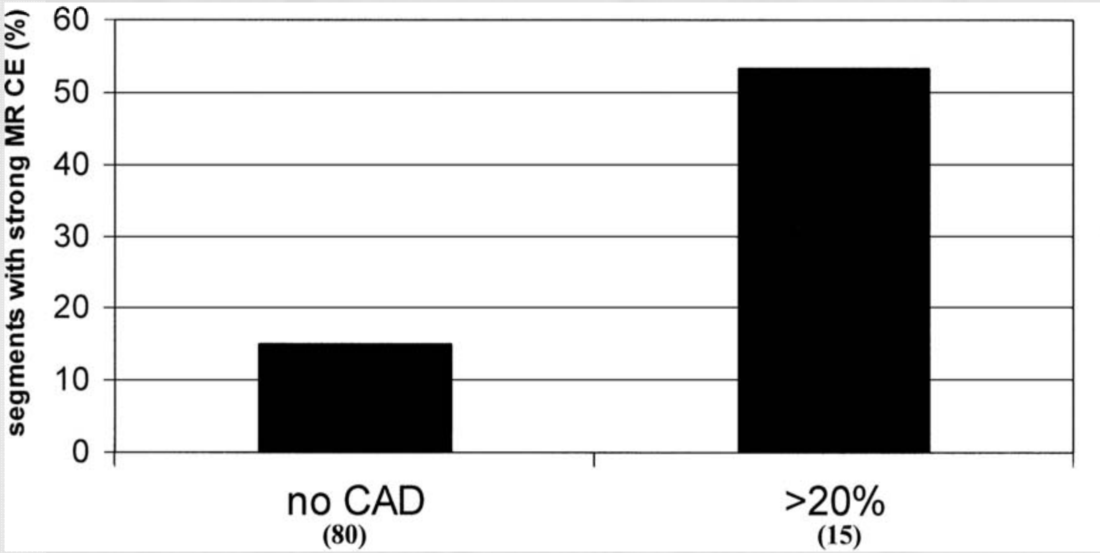


Scott et al. JMRM 2011

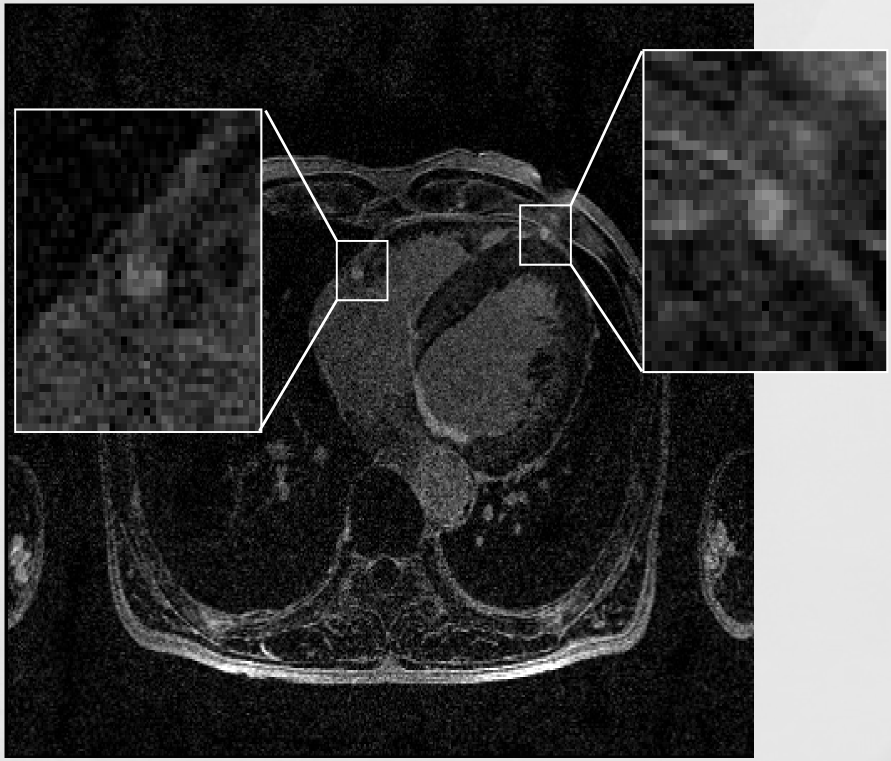
Vessel wall and plaque imaging (II)

Using Black blood technique

- Vessel wall thickness ↑
- Wall enhancement: ↑ enhancement in CAD segments
- High intensity plaque



Yeon, SB. et al. J Am Coll Cardiol 2007;50:441-447



AMC case

Vessel wall and plaque imaging (III)

- Vessel wall thickness ↑
- Wall enhancement
- High intensity plaque α positive remodeling, ultrasound attenuation, spotty calcification in the IVUS.

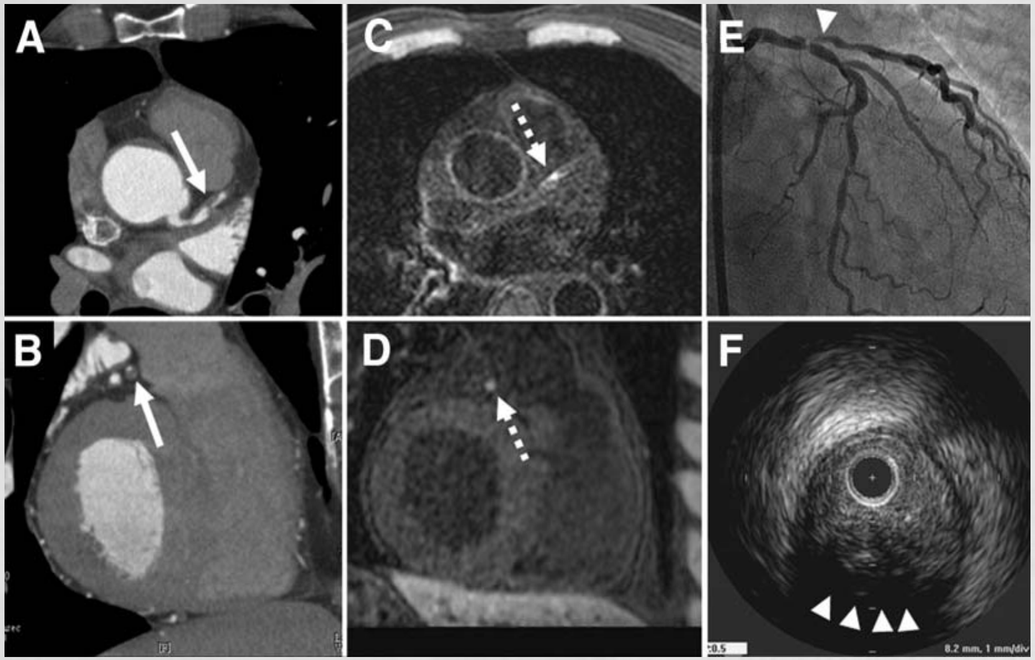


Table 3. Characteristics in Hyperintense and Normointense Plaque

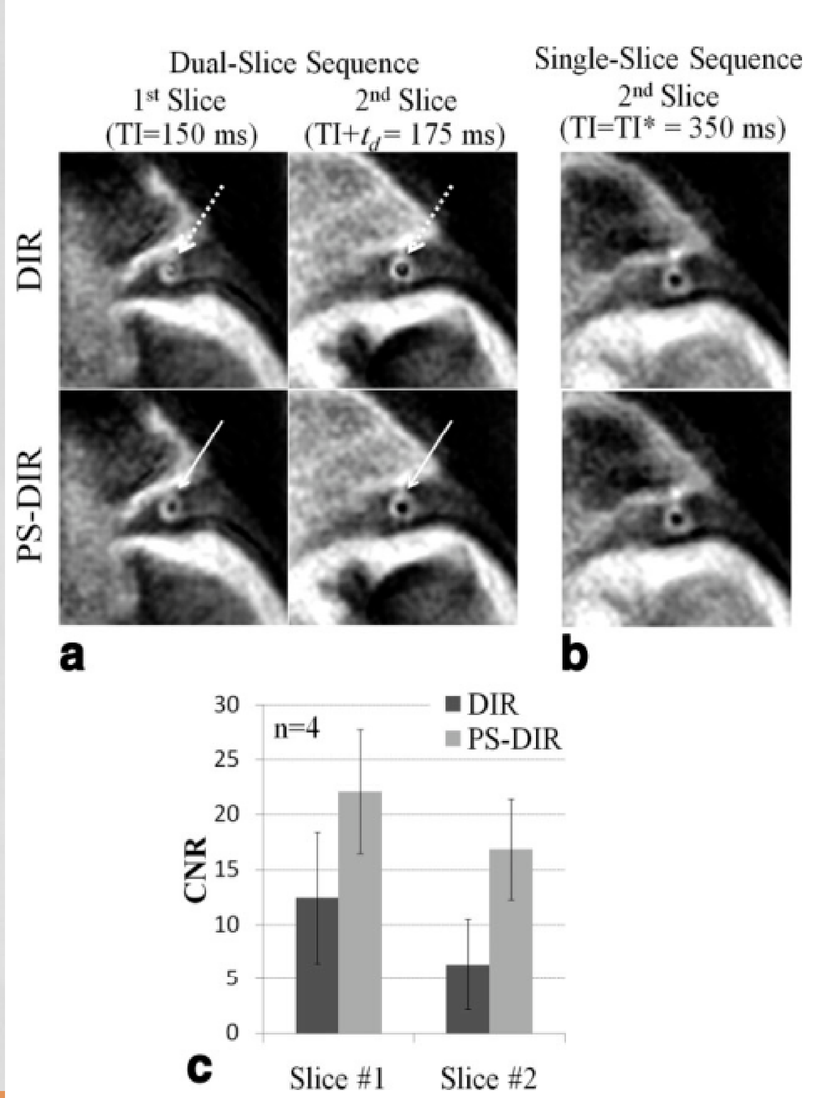
	HIP (n = 18)	Non-HIP (n = 7)	p Value
PMR	1.70 ± 0.71	0.90 ± 0.08	0.0081
MSCT			
Positive remodeling, yes/no	16/2	0/7	<0.0001
RI	1.19 ± 0.08	0.98 ± 0.05	<0.0001
Minimal CT density, HU	–23.2 ± 20.7	9.6 ± 20.5	0.0016
Spotty calcification, yes/no	16/2	3/3*	0.079
IVUS			
Positive remodeling, yes/no	17/1	1/6	<0.001
RI	1.15 ± 0.07	0.89 ± 0.11	<0.0001
Ultrasound attenuation, yes/no	18/0	1/6	<0.0001
Slow flow phenomenon, yes/no	15/3	1/6	0.003

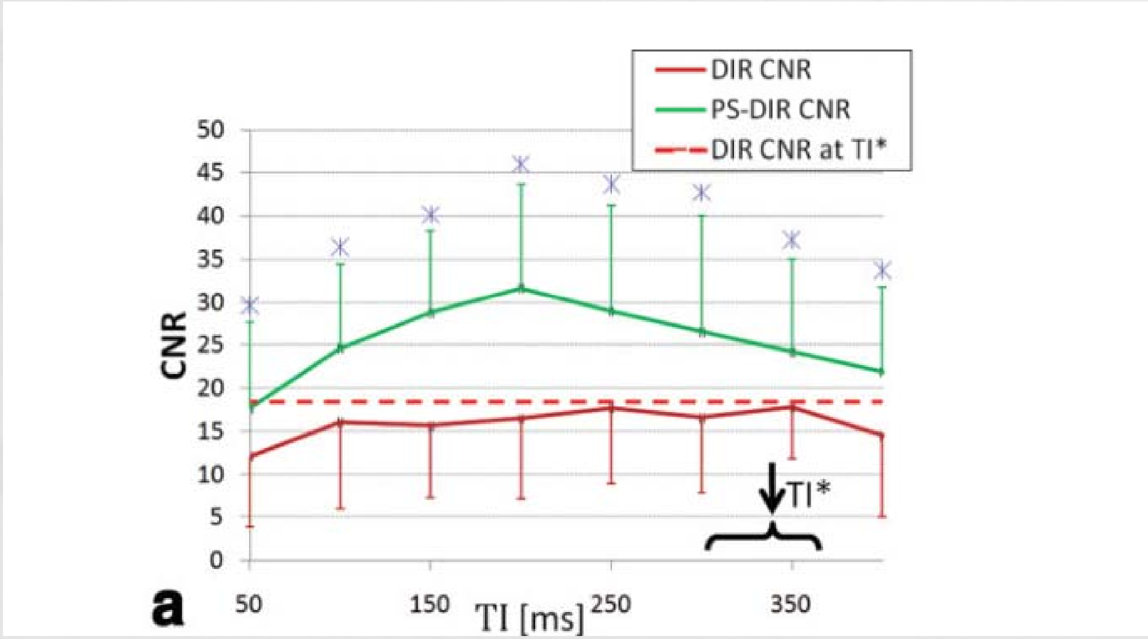
*One excluded because of large calcification.
Abbreviations as in Tables 1 and 2.

Kawasaki et al. J Am Coll Cardiol CV Imaging 2009

Vessel wall and plaque imaging (IV)

- Phase sensitive BB- imaging using 3-T: better CNR

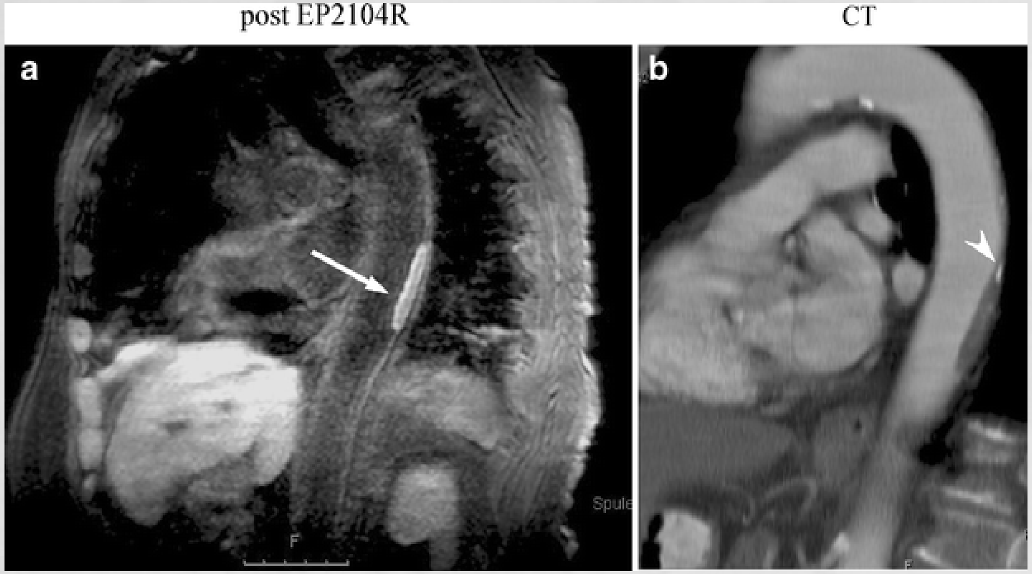


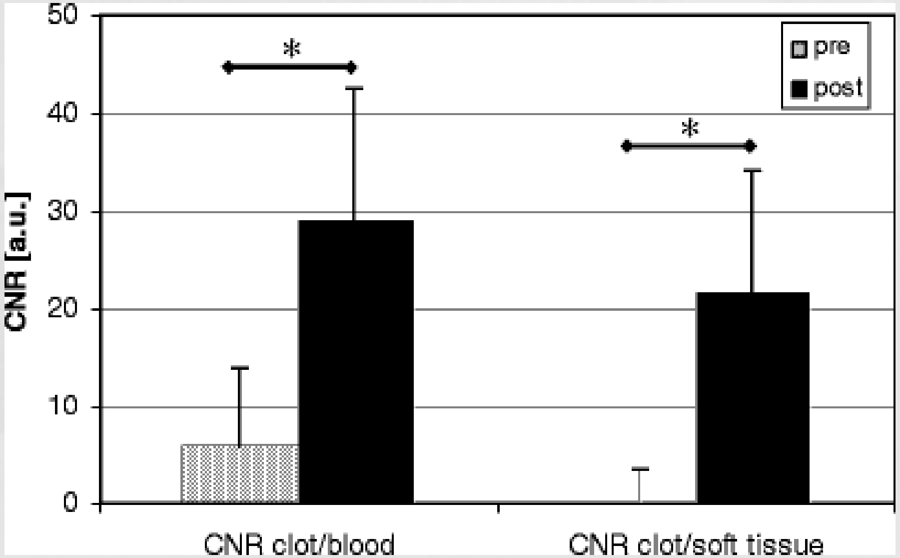


Khaled et al. MRM 2010;63:1021-1030

Molecular targeted MRI

- Targeted agents
  - Specific plaque components
  - →Fibrin in thrombi: EP-2104R
  - →Macrophage: SPIO

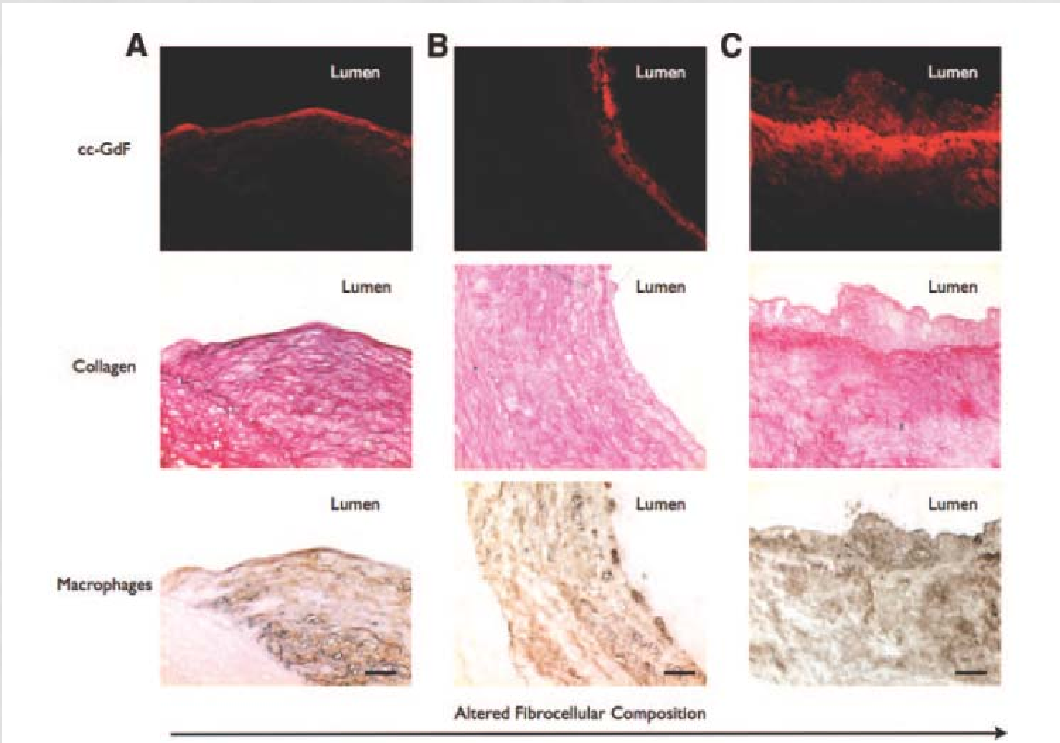




Spuentrup, Botnar, et al. Eur Radiol 2009;18:1995

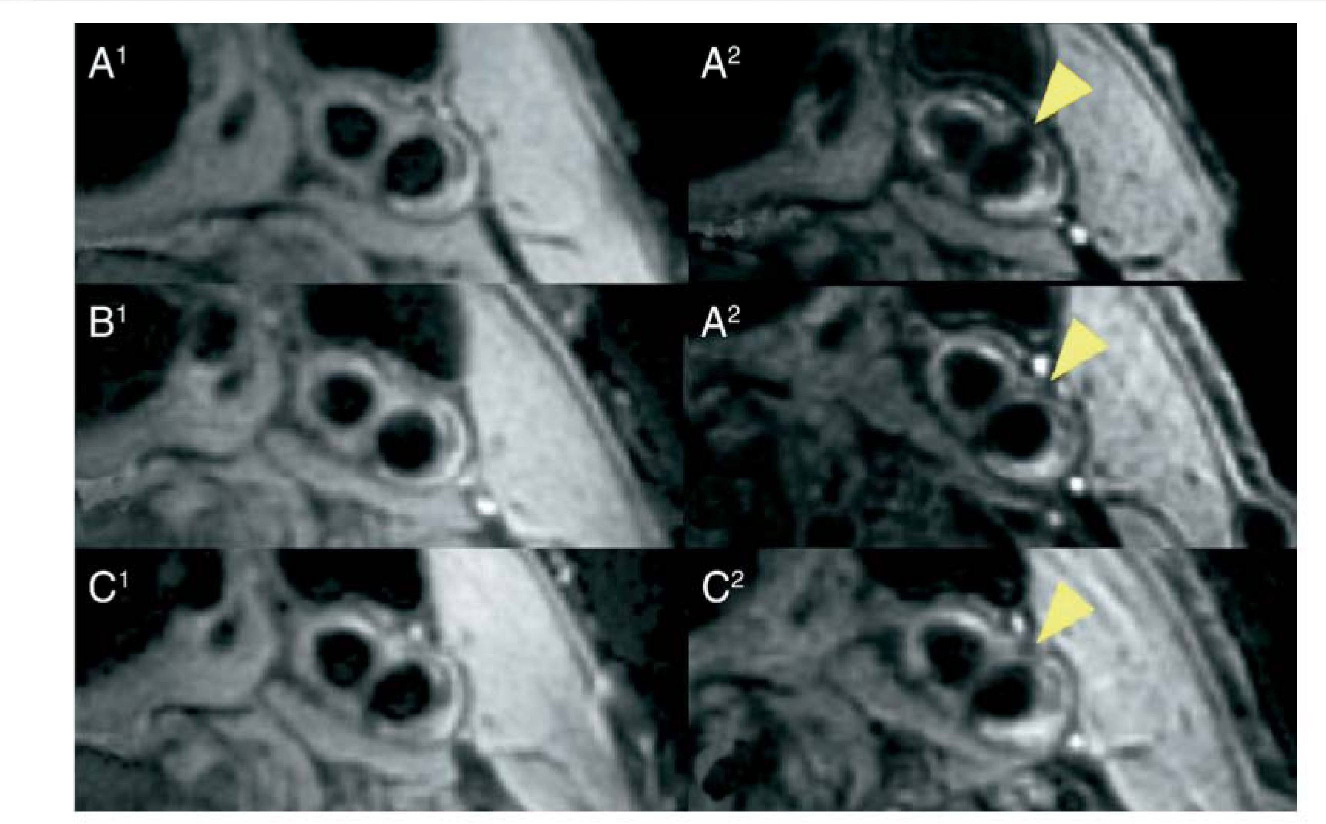
Specific contrast media

- Gadofluorine (Circ Imaging, 2009)
  - GdF was uptaken RAM-11(macrophages) and CD-31 (endothelial cells) 24 hour after administration.
  - GdF accumulates in highly inflamed, lipid-rich cores.



Plaque imaging using SPIO

- Decrease USPIO uptake after statin use (Tang, JACC 2009)



Conclusions

- Perspectives of MR coronary imaging
  - Development of fast acquisition
  - Reducing motion
  - Quantification methods
  - Plaque imaging, molecular imaging, tissue charaterization