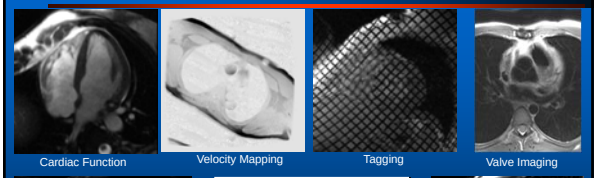
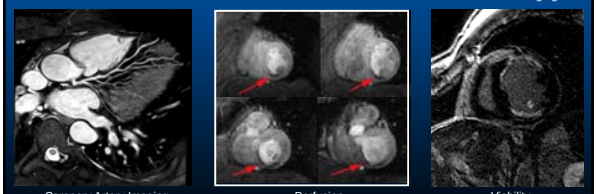
Cardiac MRI

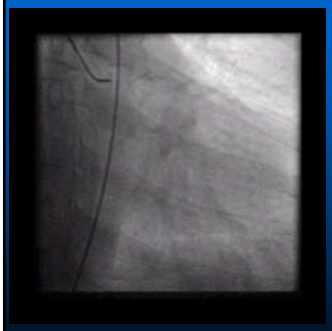
O. Wieben
Depts. of Radiology and Medical Physics
University of Wisconsin-Madison

Cardiac MRI


Cardiac Function | Velocity Mapping | Tagging | Valve Imaging


Coronary Artery Imaging | Perfusion | Viability

What is special about cardiac MR?



Dealing with motion
- Cardiac motion
- Breathing

Adjust sequences accordingly
- ECG Gating
- Breathhold – Navigator
- Rapid Imaging

X-ray DSA Matrix: 512x512, 30 frames/s

Outline

Physiological Monitoring
- ECG Gating
- Breathholds and Navigators

Sequences
- Bright Blood: Gradient echo sequences
- Phase Contrast Imaging
- Dark Blood: Double IR
- Perfusion
- Viability
- Tagging
- Coronary Imaging

1.5T vs. 3T

Not covered: CE-MRA and NCE-MRA

Cardiac MRI

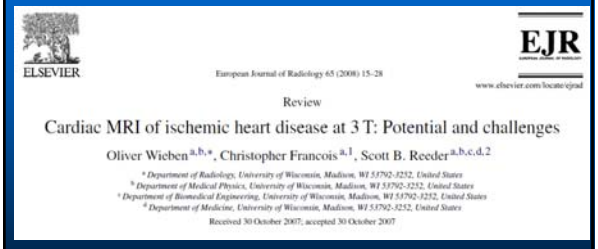
Cardiac Function, Anatomy
Myocardial Perfusion
Myocardial Viability, Infarct Size
Valvular Heart Disease
Tagging
Coronary Angiography
Plaque Imaging and Composition
T1 mapping
Interventional Imaging
Stem Cell Tracking

Clinically applied

Getting there ??

64 Slice CT competition ?

Predominantly Research


ELSEVIER

European Journal of Radiology 65 (2008) 15–28

EJR

www.elsevier.com/locate/ejrad

Review

Cardiac MRI of ischemic heart disease at 3 T: Potential and challenges

Oliver Wieben[a,b,*], Christopher Francois[a,1], Scott B. Reeder[a,b,c,d,2]

[a] Department of Radiology, University of Wisconsin, Madison, WI 53792-3252, United States
[b] Department of Medical Physics, University of Wisconsin, Madison, WI 53792-3252, United States
[c] Department of Biomedical Engineering, University of Wisconsin, Madison, WI 53792-3252, United States
[d] Department of Medicine, University of Wisconsin, Madison, WI 53792-3252, United States

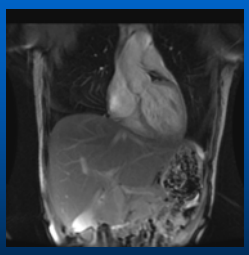
Received 30 October 2007; accepted 30 October 2007

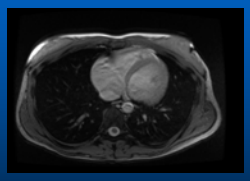
Getting ready

Position coil correctly
Get a good ECG signal
- Vector ECG
- Wireless ECG

Physiological Monitoring

Breathing Motion



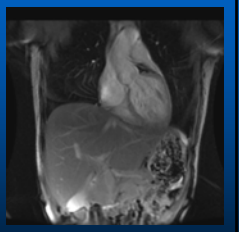


Temporal resolution: 0.3s
Playback: 3x accelerated

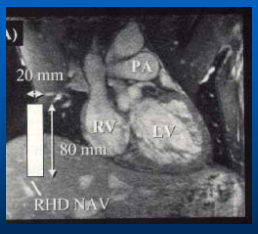
Deal with Breathing Motion

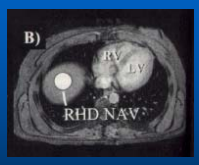
Breathhold
- End-inspiration
- End-expiration
- Limits scan time to 10-20s
- Not feasible for some patients

Free breathing
Bellows
Navigators
Beat the motion – realtime MRI



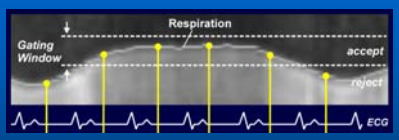
Navigator Position

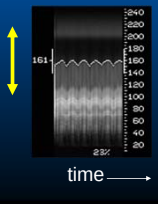




Stuber, Manning et al. JMRI 10:790-799 (1999)

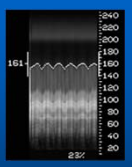
Navigator (Bellow) Analysis





Gating window: 4-6 mm
Widen window with slice tracking
Efficiency for coronaries: 40%

Navigator – Potential Issues



Low temporal resolution
- Once per RR interval

Interrupt steady state sequences

Do not directly measure motion of the heart
- Measure diaphragm position instead

Limited precision

Cine vs. Non-cine

Cine

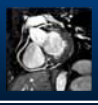
Cardiac function
Phase contrast
Tagging

ECG

t/s

Non-cine

Coronaries
Viability
Double & Triple IR



ECG

t/s

Shortest Scan duration

ECG

t/s

0 1

Example

Heartrate = 60bpm
RR cycle = 1s
TR = 3.3ms
Acquisition matrix: 256x192
Parallel Imaging: acceleration x 2

Shortest Scan duration

ECG

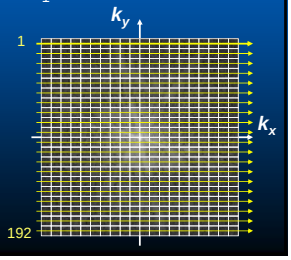
t/s

0 1 256 1

Example

Heartrate = 60bpm
RR cycle = 1s
TR = 3.3ms
Acquisition matrix: 256x192
Parallel Imaging: acceleration x 2

Total scan duration:
96*TR = 310 ms
Temporal resolution: 310 ms



Shortest Scan duration

ECG

t/s

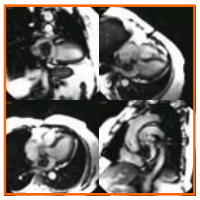
0 1 256 1

Example

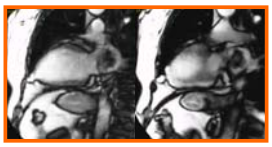
Heartrate = 60bpm
RR cycle = 1s
TR = 3.3ms
Acquisition matrix: 256x192
Parallel Imaging: acceleration x 2

Total scan duration:
96*TR = 310 ms
Temporal resolution: 310 ms

Myxoma: Fast localization and Acquisition



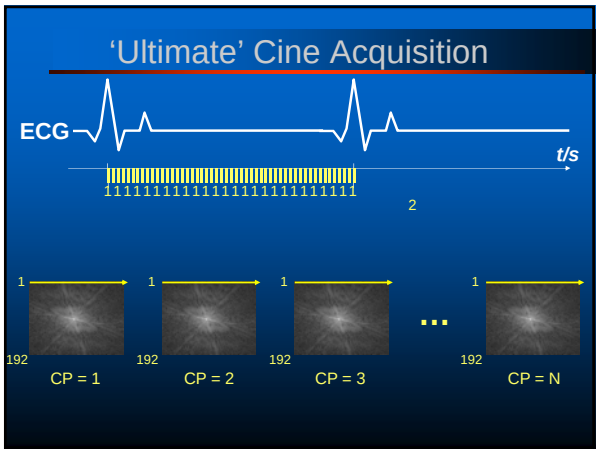
Real Time series



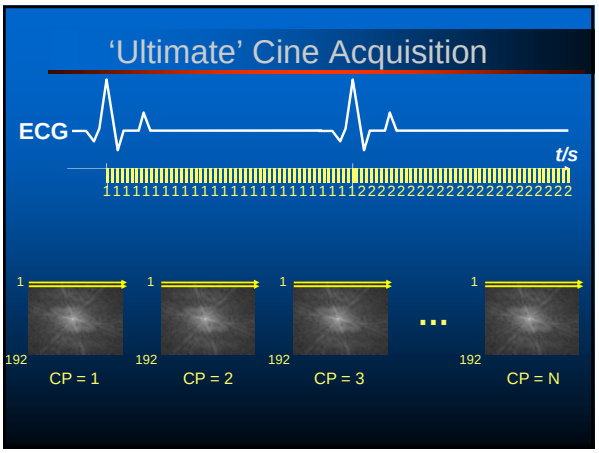
"Scan & Save" series

Image courtesy Dr Sablayrolles, Centre Cardiologique du Nord

‘Ultimate’ Cine Acquisition



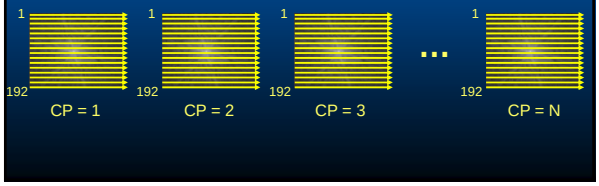
‘Ultimate’ Cine Acquisition



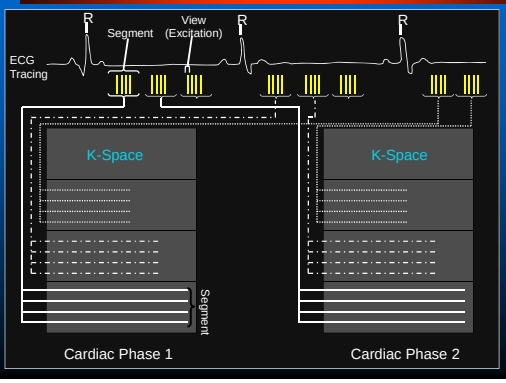
‘Ultimate’ Cine Acquisition

Example
- Heartrate = 60bpm
- RR cycle = 1s
- TR = 3.3ms
- Acquisition matrix: 256x192
- Parallel Imaging: acceleration x 2

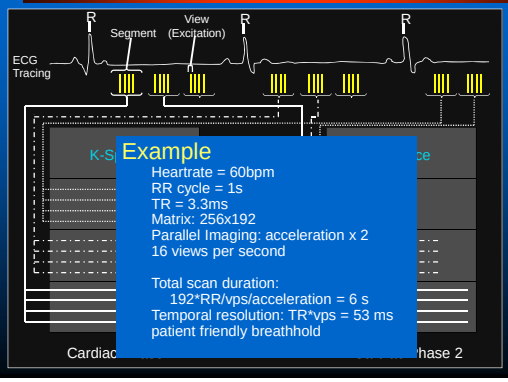
Total scan duration:
96*RR = 96 s
Temporal resolution: 3.3 ms



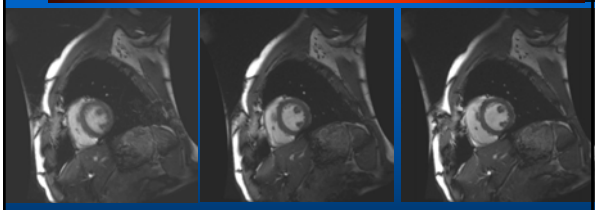
Segmented k-space acquisition



Segmented k-space acquisition

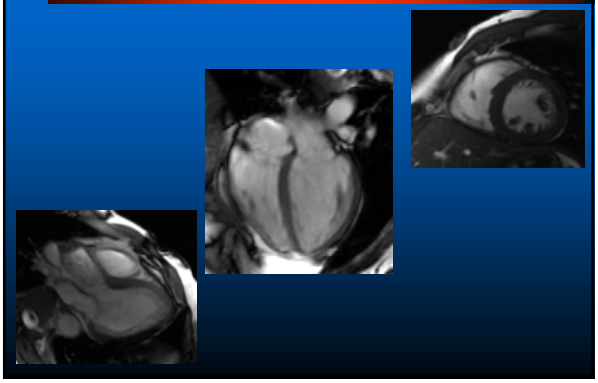


Comparison – Segmented Acuisitions



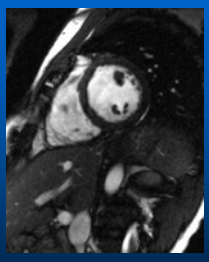
VPS = 64	VPS = 16	VPS = 4
Scan time = 3 s	Scan time = 9 s	Scan time = 43 s
Temporal res. = 211 ms	Temporal res. = 52.8 ms	Temporal res. = 13.2 ms

Cardiac Function



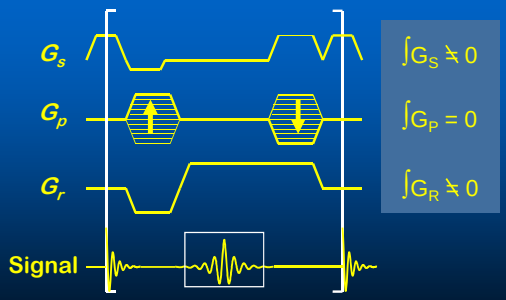
Cardiac Function: Sequences

Spoiled Gradient Echo
- SPGR – GE
- FLASH – Siemens
- FFE - Philips

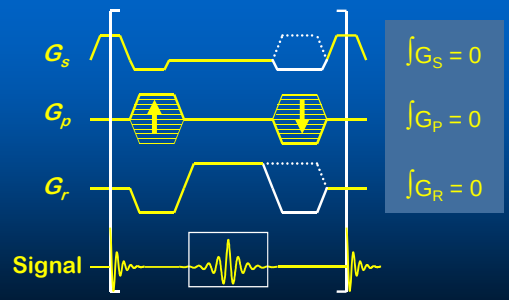


Balanced Steady State Free Precession
- FIESTA – GE
- trueFISP – Siemens
- Balanced FFE - Philips

SPGR vs. bSSFP: Sequence



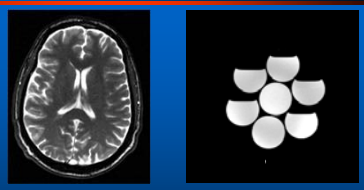
SPGR vs. bSSFP: Sequence



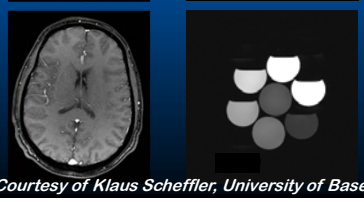
A. Oppelt et al., 1986

SPGR vs. bSSFP: Contrast

bSSFP
T_2/T_1 weighted



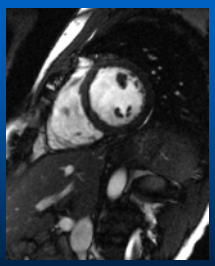
SPGR
T_1 weighted



Courtesy of Klaus Scheffler, University of Basel

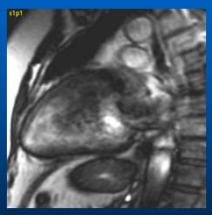
SPGR vs. bSSFP: Cine

FLASH
$\alpha = 20$



TrueFISP
$\alpha = 70$

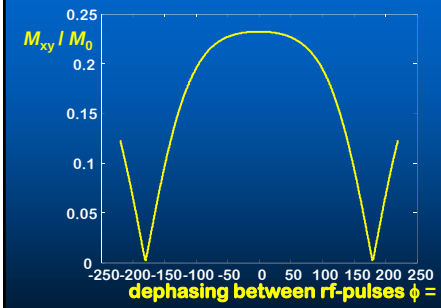
Off-resonance



Off-Resonance Artifact

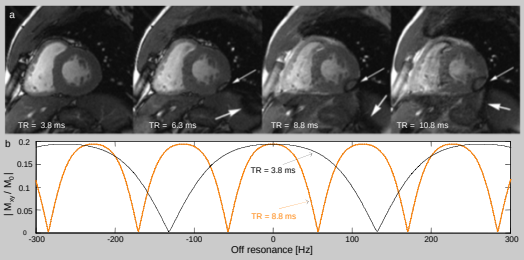
Corrected by re-shimming

Banding Artifacts with bSSFP

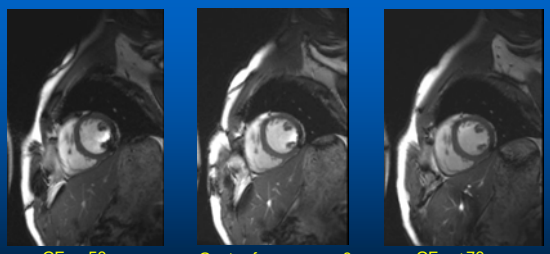


avoid bandartifacts!
TR < 5 ms (1.5 T)

Effect of TR

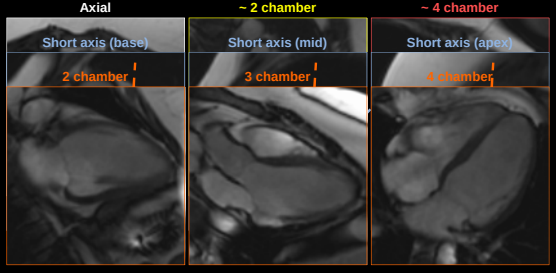


Adjusting Center Frequency

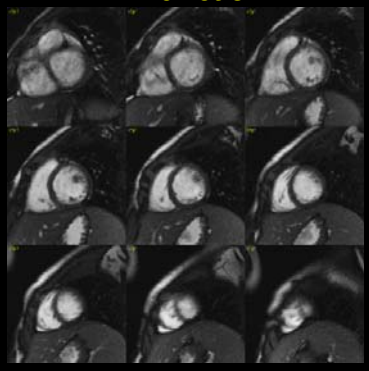


CF = -50 | Center frequency = 0 | CF = +70

Standard CMR imaging planes

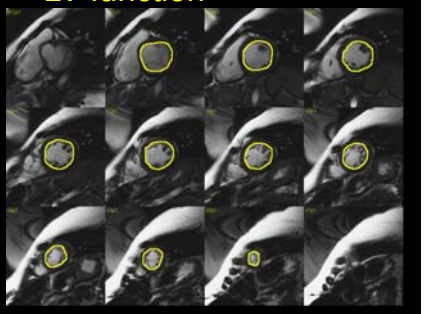


LV function

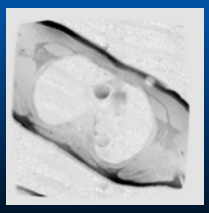


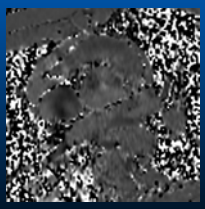
LV function

Duchenne MD
LV EDV: 144mL
LV ESV: 69mL
LVEF: 52% (50-70)
LV EDV Index: 84mL/m²
Normal: 50-84 mL/m²
LV ESV Index: 40mL/m²
Normal: 17-37 mL/m²

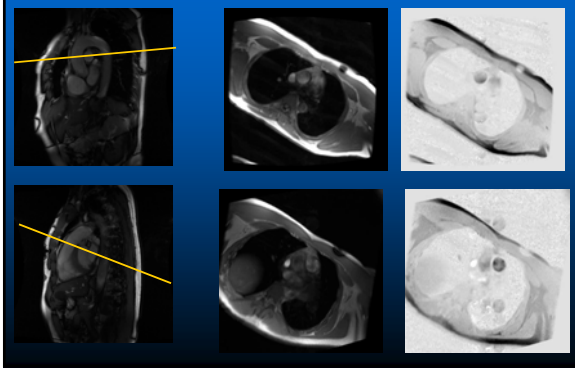


Phase Contrast Imaging

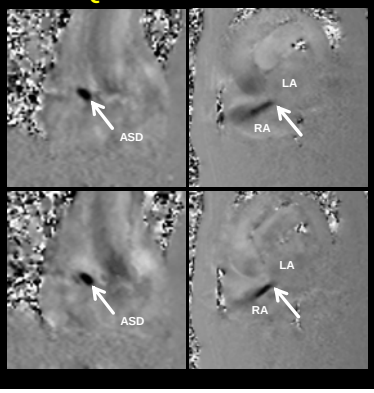




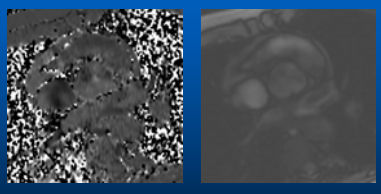
Qp / Qs measurement



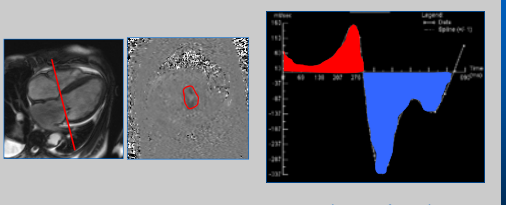
Qualitative flow



PC Valve Imaging

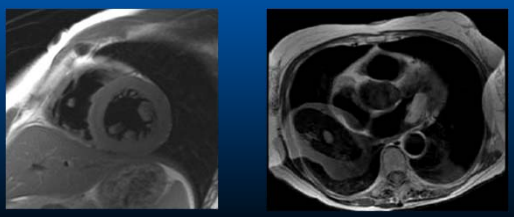


Flow Analysis

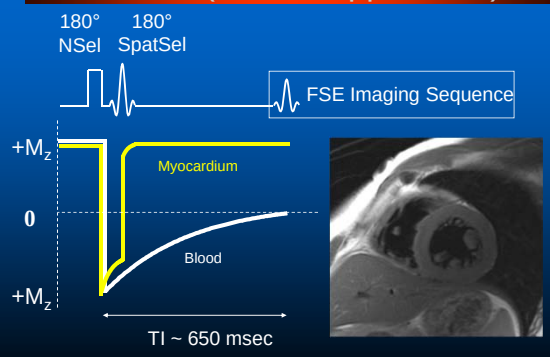


Courtesy of C. Francois, UW-Madison

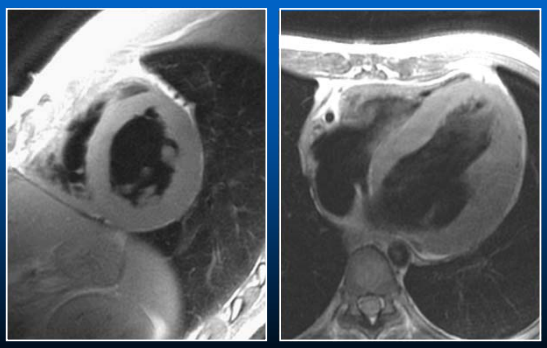
Dark Blood Imaging



Double IR (Blood Suppression)



Double IR: Short and Long Axis Views



Double IR: Vessel Wall Imaging

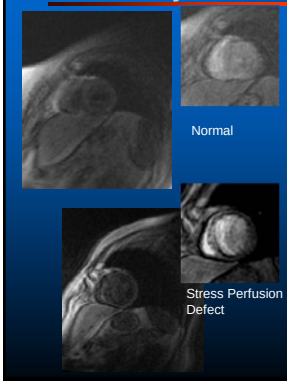
Double IR: Valve Imaging

Summary: Dark Blood Cardiac Sequences

- Employ ECG-gated, segmented, fast spin echo sequences
- Allow acquisition of multiple slices and a single cardiac phase for each slice
- May employ double inversion for blood suppression or triple inversion for blood and fat suppression
- Provide better soft tissue contrast than GRE sequences
- Used for assessing anatomy/cardiac structure – masses, thrombi, acute or remote myocardial infarctions, valves, vessel walls, etc.

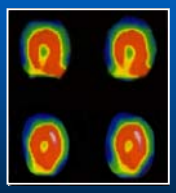
Myocardial Perfusion

Myocardial Perfusion

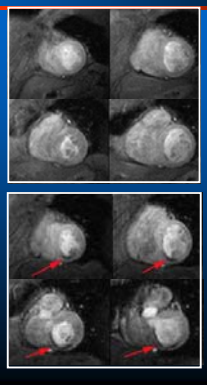


- First pass imaging during injection of contrast agent
- Sequences:
  - multiecho GRE,
  - single echo GRE with parallel imaging
- Inject 0.05 mmol/kg at 4-5 ml/second
- 5-6 Slices in SA
- Stress/Rest using adenosine (dipyrimadole) and reversing with aminophylline
- T_2^* artifact especially in septum

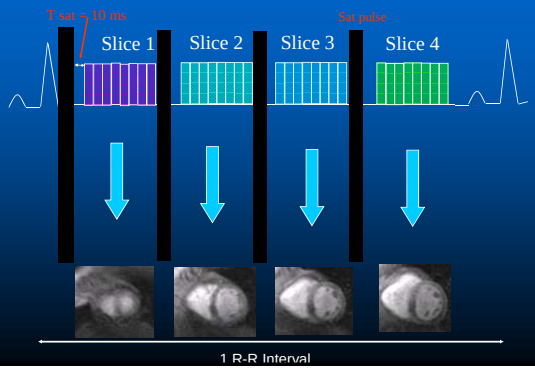
Stress Myocardial Perfusion



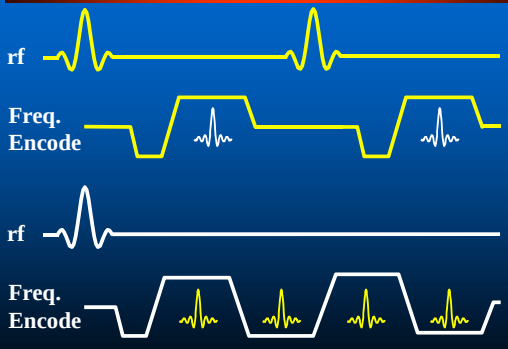
Nuclear Medicine



Saturation Recovery Sequence

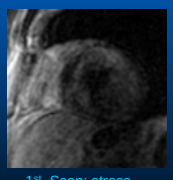


1 vs 4 echo train length (ETL)



Perfusion - Artifacts

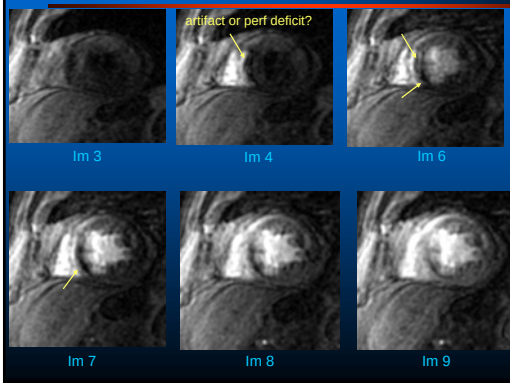
- Clinical routine at 1.5 T:
  - Patient is imaged under stress, then reverted and imaged again
  - FGRET sequence



1st Scan: stress FGRET

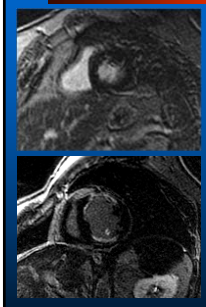
2nd Scan: rest FGRET

Perfusion - Artifacts



Viability Imaging
Late Gd Enhancement (LGE)
Myocardial Delayed Enhancement (MDE)

Myocardial Delayed Enhancement

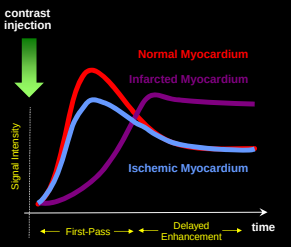


- Inject T1 shortening contrast agent
- Wait several minutes
- Image using an ECG-gated, segmented, gradient echo, inversion recovery sequence, with a TI to null non-enhanced myocardium
- Necrotic myocardium will be hyper-intense

Late gadolinium enhancement

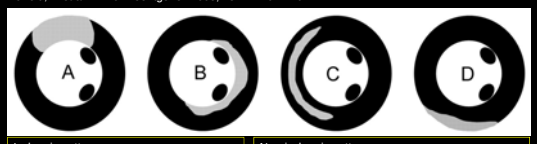
Basic cardiac MRI procedure

1. **Scout images**
2. **Cine SSFP images**
3. **Inject gadolinium contrast**
   - **± Perfusion**
   - **± MRA**
4. **Wait 10-15 minutes**
   - **± Valve imaging**
5. **Delayed enhancement images**



LGE patterns

Hunold, P. et al. Am. J. Roentgenol. 2005; 184: 1420-1426.



Ischemic patterns:

A – Transmural DCE
- Transmural infarct

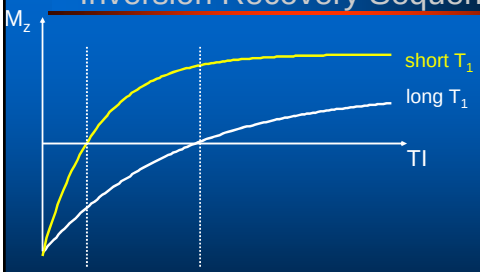
B – Subendocardial DCE
- Subendocardial infarct

Non-ischemic patterns:

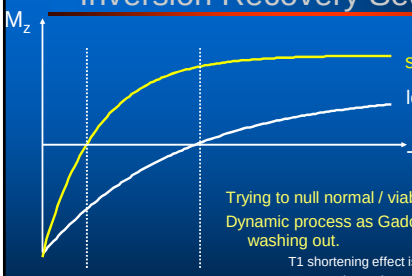
C – Midmyocardial DCE
- Dilated cardiomyopathy (DCM)
- Myocarditis
- Hypertrophic cardiomyopathy (HCM)
- Restrictive cardiomyopathy (RCM)
- RV pressure overload

D – Subepicardial DCE
- Sarcoidosis
- Myocarditis

Inversion Recovery Sequence



Inversion Recovery Sequence



Trying to null normal / viable myocardium

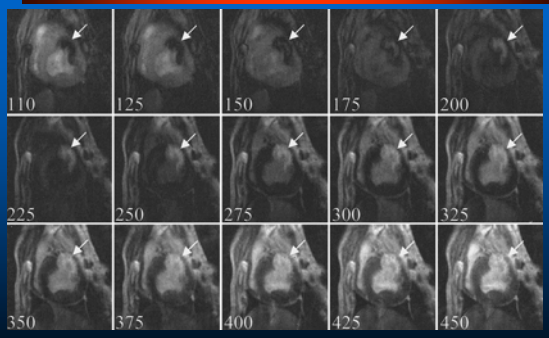
Dynamic process as Gadolinium is constantly washing out.

- T1 shortening effect is always decreasing
- T1 curve is moving to right
- Need to keep increasing TI (inversion time)

Options:

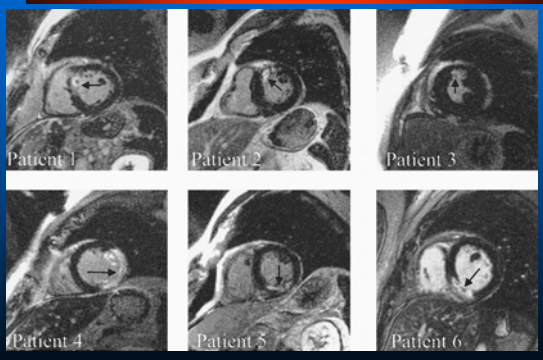
- Trial and error – currently (TI of 180 ms at 10 mins)
- Scout sequence to choose best TI
- Phase Sensitive Inversion Recovery (PSIR)

Estimating Inversion Recovery Time



Simonetti, O. P. et al. Radiology 2001;218:215-22

Examples

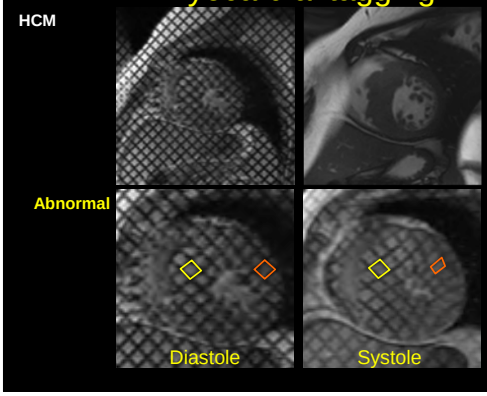


Simonetti, O. P. et al. Radiology 2001;218:215-22

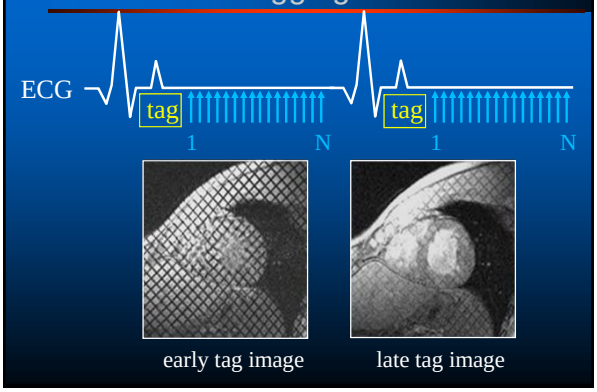
DE @ 3T

Subendocardial enhancement in the lateral wall from base to apex

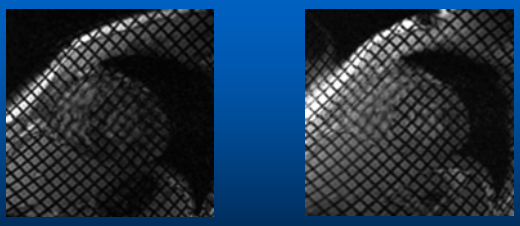
Myocardial tagging



Tagging



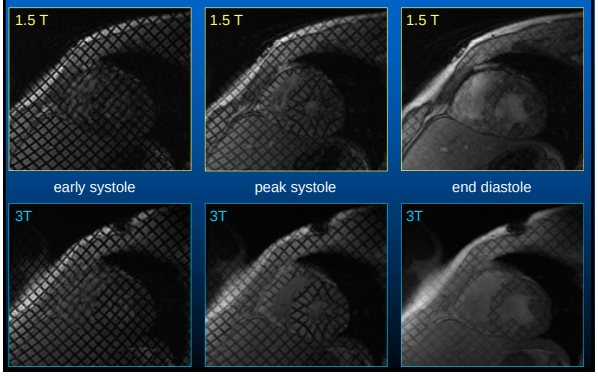
Subject 3 – Tagging SA



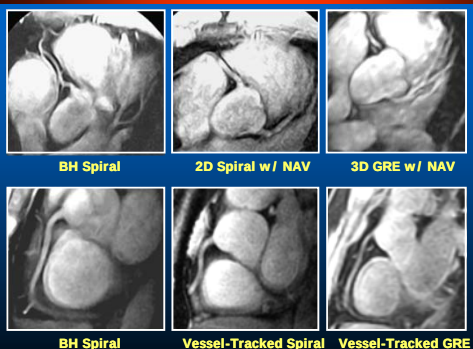
1.5 T

3T

Subject 3 – Tagging SA



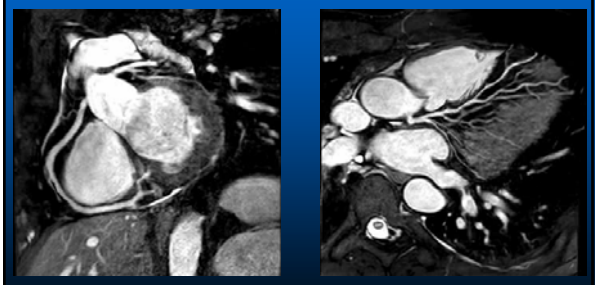
Coronary Artery MRA



Images courtesy of: Dr. Vince Ho, Uniformed Services University of Health Sciences

3D bSSFP Coronary Imaging

RCA LCA



Courtesy: Marc Kouwenhoven

Acknowledgements

University of Wisconson-Madison
Chris Francois, MD
Frank Korosec, PhD
Frank Thornton, MD
Charles Mistretta, PhD
Scott Reeder, MD, PhD
Tom Grist, MD
Jing Liu, PhD

GE Healtcare
Stuart Clarkson

Harvard Medical School
Dana Peters, PhD

University Clinics Freiburg, Germany
Oliver Speck, PhD
Bernd Jung, PhD

University of Basel, Switzerland
Klaus Scheffler, PhD