Cardiac Imaging at 3.0T

SCBT/MR
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Disclosure

• Advisory boards of Bayer, GE Healthcare
• UW receives support from GE and Bracco
• Spouse is an employee of GE
Off-Label Disclosures

- Off-label uses of Gadolinium contrast
- Investigational Pulse Sequences
Outline

• Key Pulse Sequences
  – Motion: Function and Tagging
  – Perfusion
  – Viability Imaging

• Physics between 1.5T and 3.0T is different
  – Opportunities: Why image at 3T??
  – Challenges and Solutions
Motivation: Imaging of Ischemic Heart Disease

• 1.5 million US residents have myocardial infarctions each year - 1/3 die

• Over past 30 years, dramatic reduction in the death rate from CAD – still accounts for 22% of all deaths.

• Coronary catheterization plays a major role
Balanced Steady-State Free Precession

- Optimal for CINE Cardiac Imaging
  - Highest SNR efficiency (2.5-3x spoiled gradient echo)
  - Tremendous blood-myocardial contrast
  - Very fast, can be gated, amenable to cardiac imaging
  - Signal depends on T2/T1: Fluid/blood appears very bright

Gold Standard (of ANY modality) for wall motion & function
Function/Motion with SSFP

Short Axis

4 Chamber Long Axis
First Pass Perfusion Imaging

• Image every 1-2 heartbeats over the entire heart during contrast bolus injection
• Detection of hemodynamically significant coronary artery stenosis
  – Rest and Stress
• Ultra-rapid $T_1$ weighted pulse sequence (TR=2-3ms)
• Parallel imaging needed to cover entire heart
• Spoiled gradient echo (SPGR, FLASH)
  – Saturation pulses used to suppress background
  – Enhancing tissue/blood appears bright due to $T_1$ weighting
First Pass Perfusion Imaging:
Myocardial Ischemia RCA Territory

Case Courtesy of H. Sakuma MD
Viability Imaging:
Inversion Recovery Spoiled Gradient Echo
Myocardial Infarction
Hibernating Myocardium

4 Chamber 3 Chamber 2 Chamber
Hibernating Myocardium

4 Chamber 3 Chamber 2 Chamber
Advantages of High Field Strength

Why use 3T for Cardiac MRI??
Physics of 3.0T MRI:

*Increased SNR*

- Higher field strength
  - Doubles SNR …
  - Increase spatial resolution
  - Opportunity to reduce scan time using parallel imaging with same SNR

- Decreases T2 and increases T1
  - Reduces SNR slightly
  - SSFP: SNR depends on T2/T1

*Overall increase approximately 1.8x*
Physics of 3.0T MRI:

*Improved CNR*

- Longer $T_1$ at 3T
  - Improved Background Suppression
  - Results in improved CNR of enhancing tissue
- 1st pass perfusion imaging
  - Improved detection of small defects
- Viability Imaging
  - Improved delineation of infarct extent

*Most important benefit of 3T cardiac imaging*
Saturation Recovery: *Perfusion*

- Overall Contrast between Enhancing and Infarct Improved because background $T_1$ longer at 3.0T
Perfusion Imaging at 3T
Perfusion Imaging at 3T
Inversion Recovery: \textit{Viability}

- $T_1$ of Enhancing Tissue relatively \textit{unchanged} at higher field strength – Oshinski et al
- Overall Contrast between Normal and Infarct Improved
Viability Imaging at 3T
Improved CNR at 3.0T

• Improved SNR alone improves CNR by 2x
• But also have improved contrast from $T_1$ effect
• Overall, Contrast to Noise Ratio improves by much larger factor, perhaps as high at 3x
  – Precise improvement difficult to measure
  – (Look for papers in the literature)
Example 1
Eosinophilic Endocarditis
Eosinophilic Endocarditis
Eosinophilic Endocarditis
Eosinophilic Endocarditis
Example 2
LV Pseudoaneurysm
LV Pseudoaneurysm

6mm slices
LV Pseudoaneurysm
Example 3
Cardiac Sarcoidosis at 3T
Other advantages
Tagging: Quantitative Motion
Tagging: Comparison of 1.5T vs 3.0T

1.5 T 1.5 T 1.5 T
early systole peak systole end diastole

3T 3T 3T
Disadvantages

Challenges of cardiac imaging at 3T
Physics of 3.0T MRI:  
*Bo Field Homogeneity*

- Increasing field strength worsens magnetic field inhomogeneity due to increased susceptibility
- Largest impact
  - Steady-State Free Precession
  - Leads to Banding and Flow Artifacts
    - Proportional to Bo inhomogeneity and TR
Cardiac SSFP

Increasing TR / Increasing Field Strength
Banding Worsens as TR and Field Strength (Bo) Increase

TR=3.8ms  6.3ms  8.8ms  10.8ms
Field Inhomogeneity Map

Short Axis Field Map

Large Focal Inhomogeneity

Reeder et al 1998 MRM
Flow Artifacts in SSFP: Bo Inhomogeneity

• If a band from Bo inhomogeneity falls in an area of very high flow …
  – Tremendous signal enhancement (>500%)
  – Signal persists out of slice
  – Leads to significant ghosting in phase encoding direction

Markl et al, MRM 2003
2003 Young Investigator Award ISM RM
Solutions for Bo Inhomogeneities

• Improved Shimming
  – Higher order shimming
    • Further development from manufacturers
  – Localized shimming

• Reduce TR
  – Asymmetric readout (partial k-space)
    • Reduces TR by 30%
  – Limit spatial resolution
  – Increase bandwidth
Localized Shimming

Images courtesy Stuart Clarkson, GEHC
Localized Shimming

Images courtesy Stuart Clarkson, GEHC
The Importance of Shimming

No Localized Shimming

With Localized Shimming
RF Heating:
Specific Absorption Rate (SAR)
**SAR:** Dependence on Amplitude vs Duration of RF Pulse

\[ \text{Flip Angle} = \Delta T \, B_1 \]

RF Pulse Duration

RF Amplitude - doubles at 3T

\[ \text{SAR} \propto \Delta T \, B_1^2 \]

4 Fold increase in SAR at 3T!!
RF Heating: Specific Absorption Rate (SAR)

• Major challenge for SSFP
  – High flip angle, short TR method
  – Shortening TR increases SAR

• Practically, this limits the maximum flip angle
  – 45° is maximum flip angle I typically can get
  – Slightly reduced blood-myocardial contrast

• New SAR monitoring software has alleviated this concern
Function/Motion - Comparison

1.5 T (60 deg)  3.0 T (45 deg)
Function/Motion - Comparison

1.5 T (60 deg)  3.0 T (45 deg)
Summary

• Improved SNR with 3T
• Improved Contrast from longer T1
  – Improved Background Suppression
• Greatly improved quality of viability and perfusion imaging
• SSFP CINE imaging no longer a challenge
• 3T is our first line magnet for cardiac imaging