Accelerated Imaging Strategies for Combined Spin and Gradient Echo (SAGE) Acquisitions

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Outline

• Parallel imaging review
• Clinical DSC MRI
• SAGE as an alternative to single echo DSC MRI
  • SMS/MB + SENSE/GRAPPA
• Other SAGE implementations
• Summary
Parallel Imaging Review

\[ F_1 = A_1 + B_1 = I_A \times C_{A1} + I_B \times C_{B1} \]

\[ F_2 = A_2 + B_2 = I_A \times C_{A2} + I_B \times C_{B2} \]

\[ F_3 = A_3 + B_3 = I_A \times C_{A3} + I_B \times C_{B3} \]

\[ F_4 = A_4 + B_4 = I_A \times C_{A4} + I_B \times C_{B4} \]
Clinical Perfusion using DSC MRI

Inject CA

Dynamic Imaging

Kinetic Analysis

Blood Volume
$T_1$ effects 
(direct interaction)

$T_2^*$ effects 
(through space)
Clinical challenge: contrast agent leakage

- Mitigate leakage effects
  - Leakage correction [1]
  - Preload dosing
    (requires two contrast injections)

- Standardized DSC-MRI protocols [2]
  - Longer TEs (25-35ms)
  - Moderate TRs (<1.5s)
  - Moderate flip angles (FA, 60-70°)
  - Preload dose: ↓ sensitivity to $T_1$ leakage effects

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Slide Courtesy: Ashley Stokes PhD, Barrow Neurological Institute
Multi-Echo DSC-MRI

- Eliminates T1 leakage effects
- Enables T1 and T2* quantification – simultaneous DSC/DCE

Quarles et al, MRI 2012
Multi-echo spin and gradient-echo (SAGE)

- Total and microvascular CBV, CBF, MTT, TTH
- Vessel size and vessel architectural imaging
- $K_{\text{trans}}$ and $v_e$
- Cellularity

REDUCED SPATIO-TEMPORAL COVERAGE WHEN COMPARED TO SINGLE ECHO EPI


Slide Courtesy: C Chad Quarles PhD, Barrow Neurological Institute
Simultaneous Multi-Slice (SMS) / MultiBand (MB)

Multiband RF Pulse

Slices must be spaced adequately apart to resolve superimposition

Extended spatial coverage with MB-SAGE when compared with Traditional SAGE
With fixed spatial coverage temporal resolution increases with MB factor
Multiband SENSE with Nyquist Ghost Correction


Accelerated whole-brain perfusion imaging using a simultaneous multislice spin-echo and gradient-echo sequence with joint virtual coil reconstruction

Joint Virtual Coil GRAPPA (JVC-GRAPPA)

# channels = 2 x N_c x N_e

N_c - number of coils
N_e - number of echoes

JVC GRAPPA Reconstruction with Phase Matching

Accelerated whole-brain perfusion imaging using a simultaneous multislice spin-echo and gradient-echo sequence with joint virtual coil reconstruction

Simultaneous multi-slice spin- and gradient-echo dynamic susceptibility-contrast perfusion-weighted MRI of gliomas

Simultaneous multi-slice spin- and gradient-echo dynamic susceptibility-contrast perfusion-weighted MRI of gliomas

SAGE-based fMRI

- SAGE-fMRI combines multi-(gradient)-echo (MGE) and spin-echo (SE) advantages
  - Less sensitive to susceptibility effects
  - Improved BOLD sensitivity via multiple echoes [1-2]
    - Quantify $T_2^*$ or echo-weighting combinations
  - Less sensitive to large draining veins
  - Improved spatial specificity via multiple contrasts

Hypothesis: SAGE-fMRI will improve signal fidelity, BOLD sensitivity, and spatial localization of activation


\[ D = 1 \times 10^{-3} \text{mm}^2/\text{s}, \zeta = 5\%, \Delta \chi = 0.264 \text{ppm} \]
Development of SAGE-based fMRI

- Advantages of SAGE-fMRI
  - Less sensitive to susceptibility effects
  - Improved BOLD CNR via multiple echoes
    - $T_2^*$ or echo-weighting combinations
  - Yet to be seen:
    - Improved spatial localization via multiple contrasts

- Future work
  - Apply SAGE-fMRI in Alzheimer’s disease using memory paradigms
  - Further improvements in optimizing multi-echo combinations
  - Biophysical basis of multi-contrast fMRI signals and noise

#s in red indicate # significant voxels for each method

Analysis by Dr. Maurizio Bergamino

Slide Courtesy: Ashley Stokes PhD, Barrow Neurological Institute
Spiral SAGE MRI

Summary

• Advantages of SAGE over single echo DSC MRI
  • Combined DCE/DSC information
  • Vessel size index / mean vessel diameter
• SMS/MB + Parallel Imaging
  • Same spatiotemporal coverage as clinical DSC MRI
• SAGE applications to fMRI for improved BOLD CNR
• Non-Cartesian implementations of SAGE for efficient k-space coverage
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