DWI of the Spinal Cord with Reduced FOV Single-Shot EPI

Drew Mitchell

MD Anderson Cancer Center

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Introduction

- Spinal cord diffusion-weighted imaging (DWI) can diagnose disorders from fiber tract damage
- Several challenges:
  - Magnetic field inhomogeneities around spine create off-resonance artifacts
  - Partial volume effects from CSF and lipid
  - Spinal cord cross section very small
  - Bulk physiologic motion from heart, breathing, swallowing, CSF pulsation
- Result is low-signal, low-resolution DW images with artifacts in spinal cord

Introduction

- Single-shot echo planar imaging (ss-EPI) most frequently used technique for DWI
  - Acquires whole k-space after single excitation pulse
  - No ghosting artifacts from motion-induced phase errors
- Long readout experiences T_2^* decay

Introduction

- Spinal cord imaging benefits from reduced FOV applications
- Reduced FOV methods decrease the readout duration and reduce off-resonance artifacts
- Excited FOV in PE direction reduced by 2D spatially selective echo-planar RF excitation pulse and 180° refocusing RF pulse
- Allows multi slice imaging and suppresses fat signal

Theory

Standard DW spin-echo ss-EPI sequence, with excitation pulse replaced with 90° 2D spatially selective echo-planar RF pulse

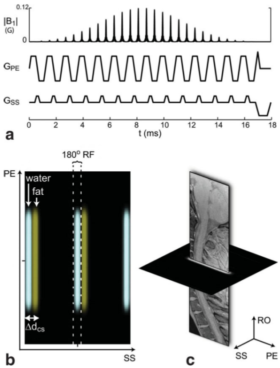
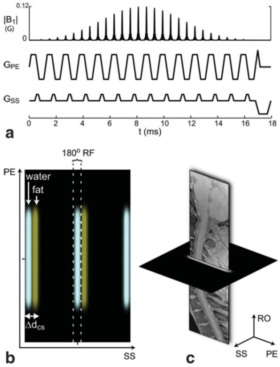


FIG. 1. (a) 2D echo-planar RF pulse and (b) simulation of the excitation profile showing how the 2D RF pulse and refocusing 180° RF pulse pair select water only in the main lobe (color coded for illustration purposes). Note that water and fat profiles are shifted by Δd_{cs} in the SS-direction. (c) The resulting water slice and slab profile shown in 3D, along with the reduced FOV image.

2D Echo-Planar RF Pulse

- 2D echo-planar pulses provide control of slice thickness in two orthogonal directions independently by combining two RF pulses
- The "slow" (blipped) and the "fast" axes gradients and RF pulses are designed to achieve desired excitation prfiles in each spatial direction



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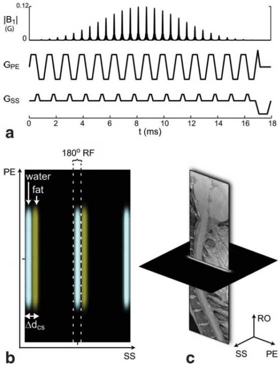
2D Echo-Planar RF Pulse

- In this paper, the echo-planar RF pulse creates a 90° flip angle over 4 mm × 4.5 cm slab
- The two orthogonal directions are the slice-select (SS) direction and the slab-select direction (phase encode direction during imaging)



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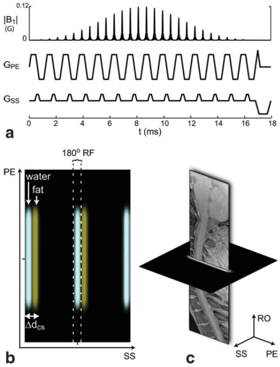
2D Echo-Planar RF Pulse

- 2D RF pulse reduces PE direction FOV to 4.5 cm, and the pulse duration is 16.8 ms
- The excitation profiles for fat and water are displaced in volume along the blipped (SS) direction



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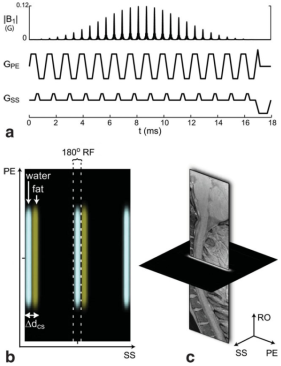
2D Echo-Planar RF Pulse

- The spatial displacement between fat and water caused by the echo-planar path of the 2D RF excitation pulse is

$$\Delta d_{CS} = \frac{N_{blip} f_{CS} T_{fast}}{K_{blip}}$$

- The displacement Δd_{CS} between fat and water can be designed so that the excited fat profile is entirely outside the water profile



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Refocusing RF Pulse

- After 2D RF excitation, a normal 180° refocusing RF pulse is used, selective in SS direction
- Crusher gradients before and after the pulse are used
- Using 2D RF excitation pulse and 180° refocusing RF pulse together suppresses signal outside lobes of periodic 2D excitation and fat signal

Multi Slice Imaging

- Multi slice imaging is not possible for FOV restriction that uses two separate 1D RF pulses, which excites adjacent slices
- 2D echo-planar RF pulses do not excite adjacent slices, making contiguous multi slice imaging possible
- Upper limit on number of simultaneously imaged slices:

$$max\left(N_{slices}\right) = \frac{\Delta d_{replicate}}{\Delta d_{SS}} = \frac{N_{blip}}{TBW_{SS}}$$

- With three sagittal slices the whole pulse sequence takes less than 120 ms per slice, allowing multi slice imaging in one cardiac cycle

Image Reconstruction

- Reduced FOV images with double resolution have quartered SNR
- This technique is more robust than multi shot techniques, because no additional navigator echo is needed