Double Inversion Recovery 3D FSE with 2D-Centric Encoding

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Introduction: Double Inversion Recovery (DIR) preparation nulls CSF and white matter [1] to image gray matter and to improve detectibility of white matter lesions [2]. Contrast due to the preparation is heavily T1 weighted. With a fast spin echo (FSE) readout, TE should be minimized to maximize SNR and to retain the full T1-weighting [3]. 3D FSE sequences with DIR [4] allow much thinner sections to be imaged, but, in order to maintain clinically practical scan times, require longer echo trains and therefore longer TEs if blurring is to be avoided. Long TEs cause a mixture of T1 and T2 weighting and reduce SNR. DIR 3D FSE with variable refocusing flip angles [5] allows very long echo trains while constraining blurring, thereby enabling single-slab 3D imaging, but also results in mixed contrast and reduced SNR due to the long TEs. We have developed a new 3D FSE view ordering method that minimizes TE and directs any signal modulation radially in k-space (and thus isotropically in image space). It allows arbitrary echo train length (ETL), decoupled from matrix size and shape, enabling elliptical k-space coverage [6] and partially parallel imaging [7] with a non-separable 2D auto-calibration region. The first purpose of this work was to determine if this 2D centric view ordering offers advantages over conventional 3D FSE view ordering [8] (which is 1D centric when TE is minimized) for DIR prepared 3D FSE. The second purpose of this work was to explore the effect of variable flip angle refocusing on resolution and SNR of centrically encoded DIR 3D FSE, specifically how direct control of the minimum refocusing flip angle [9] can be used to trade off SNR and resolution.

Methods: *Pulse sequence*—Three adiabatic inversion RF pulses prepare the longitudinal magnetization. The first two are broad bandwidth pulses, inverting all spins within the volume, and automatically timed to null both CSF and white matter at the instant of FSE excitation. The third is spectrally selective and timed (given the prior inversions) to null fat. To read out the prepared magnetization, 3D-FSE-Cube with eXtended Echo Train Acquisition (XETA) utilizes variable flip refocusing and parallel imaging acceleration factors of 3.6-3.8 with 2D-accelerated ARC (Autocalibrating Reconstruction for Cartesian sampling) [9,10].

Numerical Simulations—To compare 1D (z) to 2D (yz) centric view ordering and to explore the effects of minimum refocusing flip angle (α_{min}) and echo train length (ETL) on resolution, numerical modeling was performed with Matlab. For α_{min} varying from 15° to 180° and ETL varying from 20 to 100, 2D modulation transfer functions (MTFs) were calculated based on the view ordering and the modeled signal evolution through the echo train for a material of T1=1000ms and T2=100ms. The MTF was Fourier transformed to produce a 2D point spread function (PSF) and the full-width-at-half-max (FWHM) in the z direction was determined. Relative resolution was calculated as the ratio of the FWHM of a "flat" MTF to the FWHM of the MTF under test. SNR was normalized to that of a 180° refocusing train.

Imaging Experiments—Human imaging experiments were performed on a GE HDx 3T system. For all acquisitions, TR=6000ms, TE=15ms, and matrix=256×192×128 with the three orthogonal FOVs chosen to correspond to a $(1.2mm)^3$ isotropic resolution. For a fixed scan time of 7 minutes (corresponding to an ETL of 50), images were acquired with 1D-centric and 2D-centric view ordering, and with various α_{min} values.

Results and Discussion: Figure 1a shows the effect of α_{min} on relative resolution for three ETL values of 30, 50 and 70. In all cases, loss of resolution was considerably worse for 1D centric as compared to 2D centric. Increased minimum flip angle results in higher SNR, but also loss of resolution. Figure 1b shows how increasing ETL degrades resolution for three α_{min} values of 20°, 50° and 90°. 2D centric encoding results in a lower rate of resolution loss as ETL is increased to reduce scan time (they are inversely proportional). Figure 2 compares images acquired with a minimum flip angle of (a) 50°, and (b) 20°. With 2D centric view order, resolution loss at α_{min}=50° is isotropic and relatively minor. For α_{min} of 20°, images appear sharper, but lower in SNR.

Conclusions: 2D centric view order reduces the amount of resolution loss that occurs due to T2 decay in DIR-prepared 3D FSE. Further resolution improvement can be made by reducing the minimum refocusing flip angle and shortening the ETL, as needed given the SNR and scan time requirements of a given application.

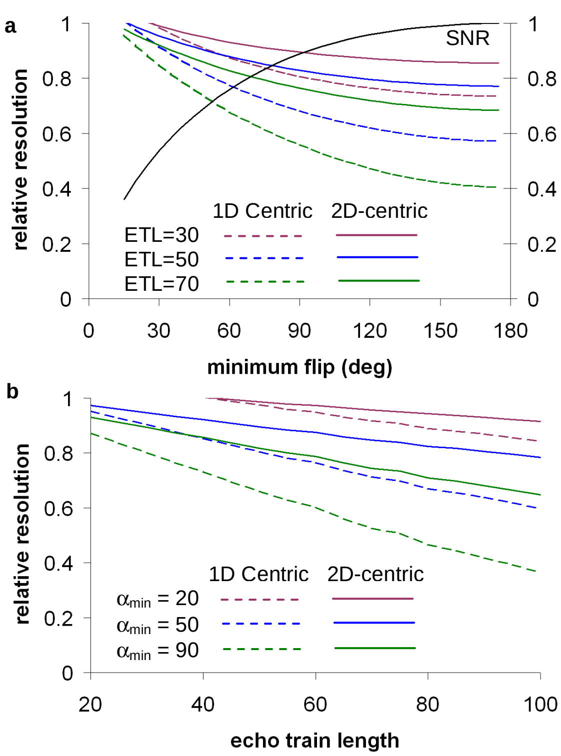

Figure 1: For a 3D FSE sequence with variable flip angle refocusing, resolution depends on (a) the minimum refocusing flip angle, which also affects SNR, and (b) the echo train length, which also affects scan time. 2D-centric produces less resolution loss than 1D-centric view ordering.

References: [1] Redpath et al BJR 1994; 67:1258-63. [2] Turetschek et al MRI 1998; 16:127-35. [3] Wattjes et al AJNR 2007; 28:54-59. [4] Boulby et al MRM 2004; 51:1181-86. [5] Pouwels et al. Radiology 2006; 241:873-79. [6] Bernstein et al JMRI 2001;14:270-280. [7] Wang et al MRM 2006; 56:1389-1396. [8] Yuan et al JMRI 1993; 3:894-899. [9] Busse et al ISMRM 2007 p1702. [10] Beatty et al. ISMRM 2007 p1749.

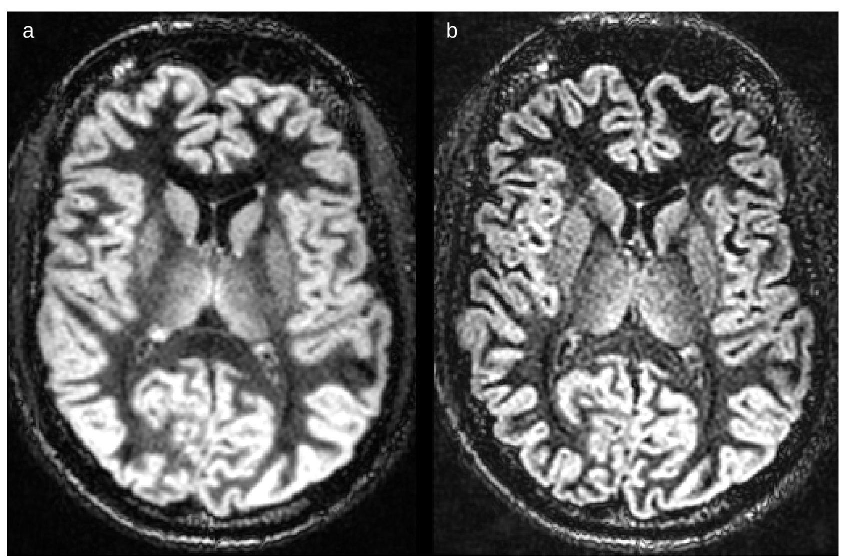

Figure 2: Axial reformats of 3D FSE acquisitions show both phase encode directions, and therefore highlight the effect of any blurring caused by long echo trains. Variable flip refocusing allows SNR to be traded against resolution by adjusting the minimum refocusing flip angle. (a) Using a minimum refocusing flip angle of 50°, SNR is higher, but blurring is evident. (b) Using a minimum flip angle of 20°, SNR is lower, but images suffer no blurring despite the relatively long echo train length of 50.