Flexible and Efficient View Ordering for 3D Sequences with Periodic Signal Modulation

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Introduction: Many 3D sequences (e.g. MP-RAGE [1] for T1w- and 3DFSE [2] for T2w-contrast) acquire multiple lines of k-space in a train while magnetization in a transient state, making view ordering an important factor in image quality. Views are usually ordered such that a kx-ky or kx-kz plane is acquired in an integer number of echo trains [1,2], while a more advanced method allows multiple planes to be acquired per echo train using separate "turbo factors" for ky and kz [3]. These methods are limited to a k-space grid that is regular and rectangular (Fig 1a), but a more flexible sampling pattern is desirable. Cutting ky-kz space corners reduces scan time by 22% [4] and for 2D-accelerated partially parallel imaging [5], a non-separable auto-calibration region is most efficient (Fig 1b). Here we demonstrate a flexible view ordering method that (a) allows the increased sampling efficiency afforded by elliptical k-space coverage and a non-separable 2D auto-calibration region, (b) enables echo train lengths to be controlled independent of matrix size, and (c) maps signal modulation into k-space smoothly so as to avoid producing image artifacts.

Methods: *View Ordering Technique* – Views are sorted into trains and echoes based on their position in k-space to produce linear or radial signal modulation in k-space. First, all acquired views are sorted by their position in the direction of desired signal modulation (e.g. ky or kr). An echo number is assigned to each view – given N trains, the first N views in the sorted list are assigned to echo 1, the next N views to echo 2, etc (Figure 2a,c). Next, views within each group assigned to a given echo number are sorted by the orthogonal phase encode direction (e.g. kz or kθ) and a train number is assigned to each view within the group (Figure 2b,d).

Imaging Experiments – The view ordering technique was implemented for 3D-FSE-Cube with eXtended Echo Train Acquisition (XETA [6]). The sequence acquires large 3D matrices in clinically practical scan times using variable flip angle refocusing RF [6,7] and 2D-accelerated autocalibrating parallel imaging (ARC [8]). Two human imaging experiments were performed on a GE HDx 3T system to compare the proposed method to a "single-shot" acquisition in which one kx-ky plane is acquired each TR: a T2w brain scan and a PD-weighted knee scan. In both cases, single-shot view ordering, in which ETL is dependent on matrix size, is compared to the proposed method with: (a) equivalent matrix size and ETL and reduced scan time, and (b) increased matrix size, optimized ETL, and equivalent scan time.

Results and Discussion: Figure 3 presents the human imaging results. For the T2w brain scans, the proposed view ordering reduced scan time from 3 min to 2 min while producing images that are indistinguishable in quality. Alternately, increasing the matrix from 256×224×128 to 320×320×128 was possible for a 3 min scan; flexible ETL allowed TE to remain fixed (93ms in all cases). For the PDw knee scans, the proposed view ordering reduced scan time from 3:45 to 2:45 and also reduced the minimum TE from 35 to 19ms, improving visualization of the cartilage. For a 3:45 scan, matrix size was increased from 256×224×128 to 320×320×128.

Conclusion: A new flexible view ordering method for 3D transient-state sequences improves scanning efficiency and decouples train length from matrix size.

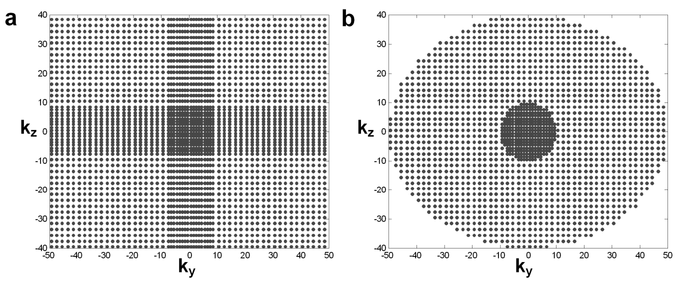

Figure 1: (a) a separable grid for 2D-accelerated autocalibrating parallel imaging, (b) a non-separable grid has 1/3 fewer views and can be acquired in less time.

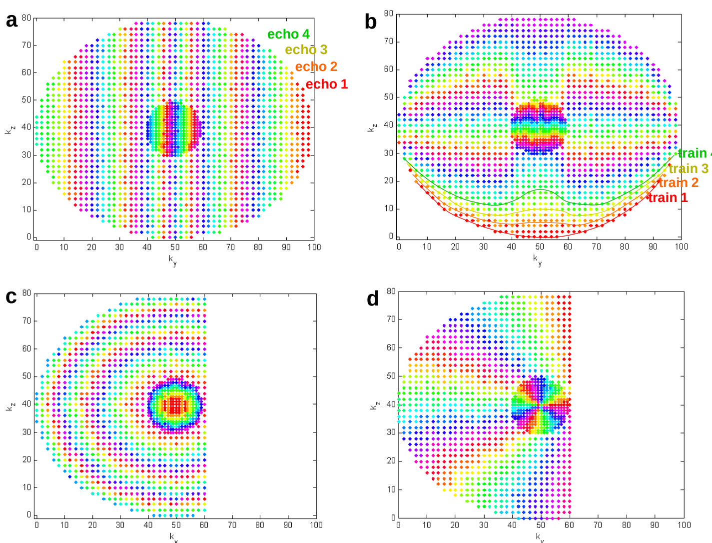

Figure 2 View order algorithm. For linear modulation: (a) Views are sorted by ky location, divided into groups, and assigned an echo number (denoted by color). (b) Views within each group are sorted by kz and assigned a train number (denoted by color). For radial modulation and half-Fourier: (c) Views are sorted first by normalized radius. (d) Views within each group are sorted by angle.

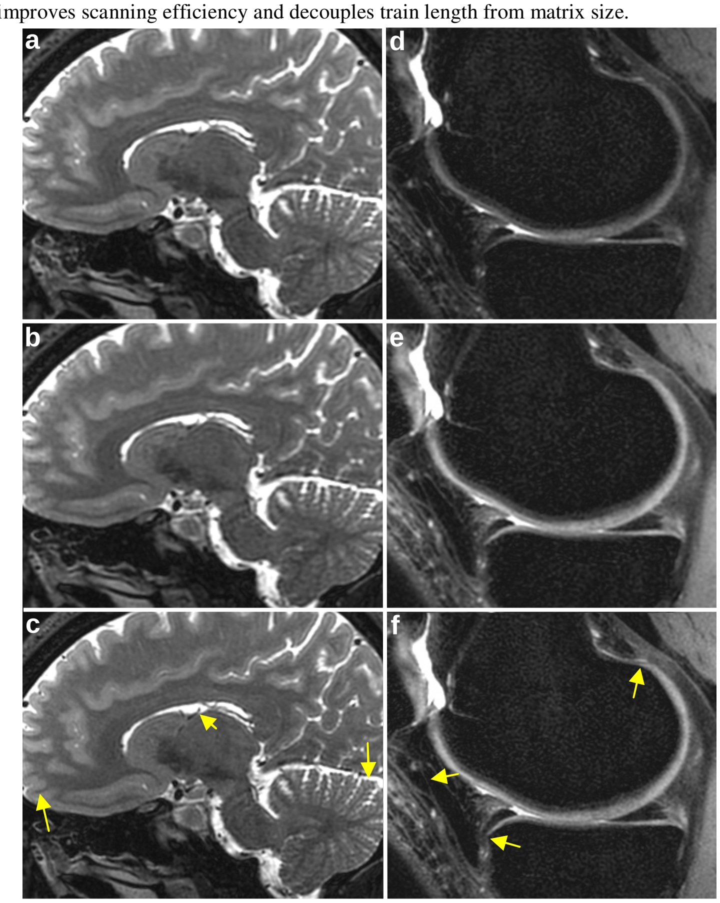

Figure 3 T2w brain: (a) single-shot view order, (b) proposed view order with same resolution in 33% less scan time, (c) proposed view order with higher resolution in same time. PDw knee: (d) single-shot view order, (e) proposed view order with same resolution in 27% less scan time, (f) proposed view order with higher resolution in same time. Enhanced detail is shown with arrows.

References: [1] Mugler MRM 1990; 15:152-157. [2] Mulkern MRI 1990; 8:557-566. [3] Mugler ISMRM 2006 p2429. [4] Bernstein et al. JMRI 2001;14:270-280. [5] Wang MRM 2006; 56:1389-1396. [6] Busse ISMRM 2007 p1702. [7] Mugler ISMRM 2000 p687. [8] Beatty ISMRM 2007 p1749.