Azimuthal Sorting in Tandem with Elliptical Reordering (ASTER): a new k-space reordering scheme for reduced motion sensitivity

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Purpose: MRI is very sensitive to motion, particularly in 3D imaging where temporally localized motion can propagate across the whole reconstructed volume. In cardiac and abdominal imaging applications, subjects are required to suspend their respiration for a period of 15-25s to minimize ghosting and blurring artifacts. Breath-holding poses difficulties in pediatric and elderly subjects and in patients with severe health conditions. Even in regions where breath-holding is not required (e.g. the brain, spine, and joints), involuntary motion is quite common especially towards the end of a long scan. We propose ASTER (**A**zimuthal **S**orting in **T**andem with **E**lliptical **R**eordering), a novel k-space reordering scheme that minimizes sensitivity to motion whilst permitting flexible combination with magnetization preparation schemes.

Theory: The central part of k-space encompasses most of the signal energy and contributes the bulk of the signal and contrast in MR imaging. In many applications, it is desirable to acquire the central k-space as quickly as possible and at an optimal time, for example following contrast injection or magnetization preparation schemes or earlier in the scan when the probability of motion is reduced. Elliptical centric (EC) view ordering [1] has been valuable in contrast enhanced MRI providing good arterial phase visualization with a high degree of venous suppression. However, motion during the acquisition (for instance due to loss of breath-hold) can cause large jumps in contiguous regions of k-space causing severe ghosting artifacts. 3D radial trajectories have shown promise for motion correction and even self-navigation [2]. However, such trajectories are sensitive to system imperfections besides the computational complexity of regridding reconstruction. In the proposed ASTER scheme (Fig 1), a central elliptical region is acquired first followed by a series of radial fan beams in the remainder of k_y-k_z space. Within each radial fan beam, points are acquired in the order of increasing k_r. All k-space points are constrained to lie on a Cartesian grid in k_y-k_z space, retaining the advantages of an alias-free fixed frequency encoding direction and a simple FFT reconstruction similar to the CAPR method proposed in [3] for time resolved imaging. We hypothesized that the radial sector segmentation would result in motion artifacts getting distributed less coherently than standard Cartesian imaging, similar to radial under-sampling artifacts. Magnetization preparation schemes could also be easily implemented using this scheme without causing large perturbations in central k-space. The limiting cases of ASTER are a pure radial acquisition on one side and a pure elliptical centric acquisition on the other.

Experiments- MATLAB simulations were performed to assess the point spread function (PSF) in the presence of motion. A quasi-periodic motion with a 5s period and a displacement of 5 pixels (left-right in Fig. 2) was modeled and its effect on sequential, EC and ASTER view ordering analyzed. ASTER k-space segmentation was incorporated into a dual-echo bipolar readout 3D SPGR sequence with a robust 2-point Dixon fat-water separation algorithm [4]. Imaging parameters were as follows: 15° flip, $\pm$167 kHz bandwidth, TR/TE$_1$/TE$_2$ 4/1.2/2.4 ms, 256x192 matrix, 26-35 cm FOV, 3-4 mm thick, 48-60 slices, self-calibrated hybrid space parallel imaging with a 2.5x1 acceleration, total scan time of 20-24s. After obtaining informed consent, subjects were imaged on a GE 3T Excite system (GE Healthcare, Waukesha, WI) using an 8-channel torso array coil. The subjects were asked to hold their breath for the initial 5 s of the scan. Following this period of elliptical centric k-space acquisition, the subjects were asked to breathe and the k-space acquisition switched to the radial fan beam segmentation for the remainder of k-space acquisition. For comparison, data were also acquired using the sequential and EC view ordering following the same breathing pattern.

Results: Figure 2 compares the motion PSFs obtained from MATLAB simulations of the three view ordering schemes. Note the lack of coherence as well as the reduced spread in the ASTER scheme (C) compared to sequential (A) and EC (B) schemes as well as the discrete nature of the ghosting in the sequential scheme compared to the more dispersed ghosting for EC and ASTER schemes. Figure 3 compares 3D datasets obtained using the three view ordering schemes on a subject who was asked to breathe after a 5s breath-hold. The total scan duration was 22s for each acquisition. A dramatic reduction in ghosting and blurring artifacts using ASTER (C,F) can be readily observed. The discrete nature of the ghosts in sequential (3A,3D) and the increased smearing in EC (3B,3E) agree with the PSF predictions. While the ASTER images do have artifacts, it is reduced compared to the other two schemes, presumably because of the better dispersal as predicted by the PSF.

Discussion: The proposed ASTER scheme effectively combines the energy capture of the elliptical centric trajectory with the motion robustness of a radial sector scan. Randomizing the order of the radial sectors can further disperse the ghosting energy. It is also possible to apply respiratory gating to acquire the central most elliptical region and then acquire each radial sector in successive respiratory cycles. This will greatly improve the efficiency of conventional navigator gated schemes, which typically acquire a fixed number of k-space encoding steps in each cycle.

References: [1] AH Wilman et al. Radiology; 205:137-146 (1997) [2] J Du et al. JMRI; 20:894-900 (2004) [3] A Madhuranthakam et al. MRM 51: 568-576 (2004) [4] Ma et al. MRM. 52:415-419 (2004)

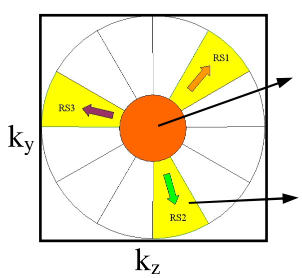

Figure 1. The proposed ASTER k-space segmentation scheme

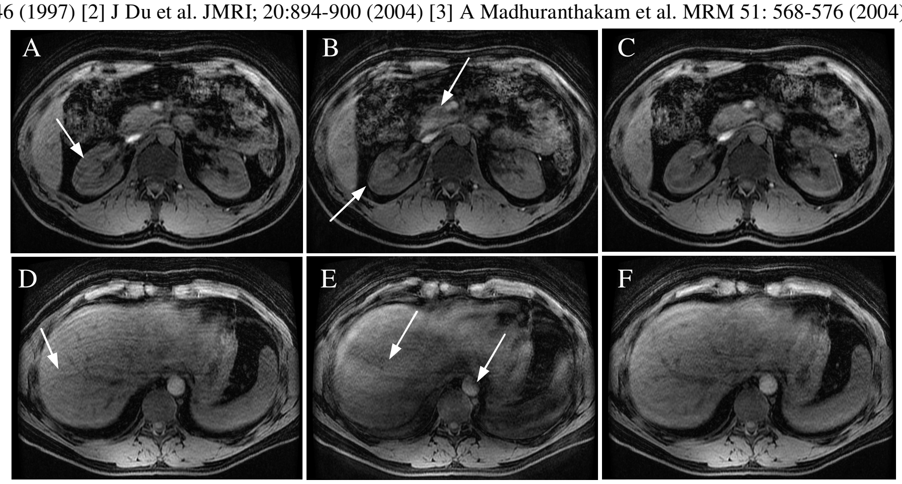

Figure 2: Motion PSF (5 pixels LR) comparisons: sequential (A), elliptical centric (B), and the proposed ASTER view ordering scheme (C).

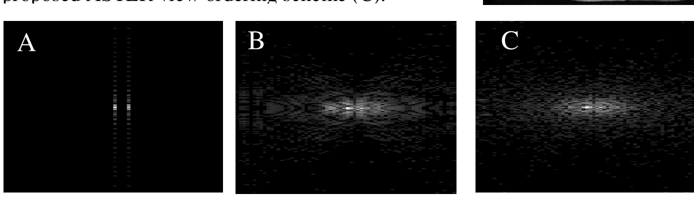

Figure 3: Comparison of representative water-only renal (top row) and hepatic/splenic sections (lower row) obtained using a 3D SPGR Dixon pulse sequence with sequential view ordering (A,D), elliptical centric view ordering (B,E), and the proposed ASTER view-ordering (C,F). Note the significantly reduced ghosting and blurring in the proposed scheme (C,F) compared to the sequential and elliptical centric schemes (white arrows)