

Navigator-based Elliptical k -Space Reordering for Aortic 4D-Flow Imaging

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Introduction

Time resolved three-dimensional phase contrast MRI (4D-Flow) simultaneously provides anatomical images and three-directional quantitative velocity information [1]. The resulting data provide a basis for advanced 3D velocity vector and flow visualization and the derivation of additional hemodynamic parameters such as pressure gradients and wall shear stress. Respiratory motion becomes a limiting factor when imaging in the torso, and long scan times make imaging during a breath hold impossible. Respiratory gating based on navigator signals or external measurements with bellows have been shown to reduce phase-related motion artifacts in long two- and three-dimensional free breathing acquisitions [3]. Moreover, real-time adaptive k -space reordering, i.e. phase encoding based on the current position in the respiration cycle, can considerably improve navigator efficiency and thus reduce overall scan time. This work builds on proven respiratory gating and compensation methods by extending them to include reordering in the 3D slice-select direction in addition to the phase-encoding direction. The aim was to improve the consistency of the data around the center of k -space, leading to improved image quality or a reduction in scan time. In addition, this reordering scheme provides a basis for implementation of elliptical k -space filling, where the corners of k -space are zero-filled for an additional 20% reduction in scan time without a reduction in spatial resolution along the primary axes of the ellipse [4].

Methods

An elliptical centric view ordering scheme [5] was implemented and adopted to acquire lines based on their radial distance from the center of the k_y - k_z plane according to the most recently acquired navigator position (Figure 1). The acquisition uses prospective ECG gating, and a navigator is acquired at the end of each R - R interval. Respiratory gating is used to reject data outside of a predefined navigator window. The relative respiration position within the window (0 at the bottom near inspiration, 1 at the top at end-expiration) was calculated for navigators within the gating window. This position was used to calculate a “desired k -space radius” from the center of k -space in the k_y - k_z plane to consistently position data acquired near end-expiration (top of acceptance window) as close as possible to the center of k -space while acquiring the outer k -space radius data at respiratory positions at the bottom of the acceptance window. If phase encodes at this radius were already measured, the sequence acquired the nearest possible k_y - k_z line.

Back-to-back in vivo 4D-Flow aortic sagittal-oblique volumes were acquired from two healthy volunteers on a 3T scanner (Siemens Trio, Erlangen, Germany). Common imaging parameters included: TR/TE = 4.9/2.4 ms, flip angle = 7°, readout = 160, k_y phase encodes = 90, k_z phase encodes = 24, bandwidth = 45.5 kHz, and VENC = 150 cm/s. Images were reconstructed on a 160x120x24 matrix with 2.0x2.0x2.2 mm³ voxels and 59 ms temporal resolution. Images were acquired with 100% data acceptance and a 4 mm respiratory gating window (50-70% data acceptance) with k_y -reordered and k_y - k_z -reordered sampling.

Results

Simulation results are shown in Figure 2 for acquisitions with no reordering (top), k_y -reordering (middle), and radial k_y - k_z reordering (bottom). The simulated results demonstrate increased data coherence in the low spatial frequencies for both reordering schemes when compared to the sequential acquisition, with the k_y - k_z reordering simulation showing improved symmetrical characteristics.

Figure 3 shows sagittal-oblique and coronal reformats of the in vivo data from one volunteer. The images in the top row were acquired with 100% data acceptance, and reordering in k_y (left) and reordering in k_y - k_z (right). Images in the bottom row were acquired with a 4 mm navigator acceptance window, again with reordering in k_y (left) and reordering in k_y - k_z (right). Respiratory motion artifacts were reduced in the k_y - k_z images for both comparisons (thin arrows).

Discussion

We successfully implemented a novel k -space reordering technique that reduces respiratory motion artifacts. In combination with parallel imaging techniques and elliptical k -space filling and omission of lines in the k -space corners, we believe we can significantly reduce scan time while maintaining adequate quality for accurate flow visualization and quantitative analysis in the aorta. The benefits of this sequence may be even larger in other applications, such as areas with more complex motion or anatomy requiring an isotropic field of view.

References

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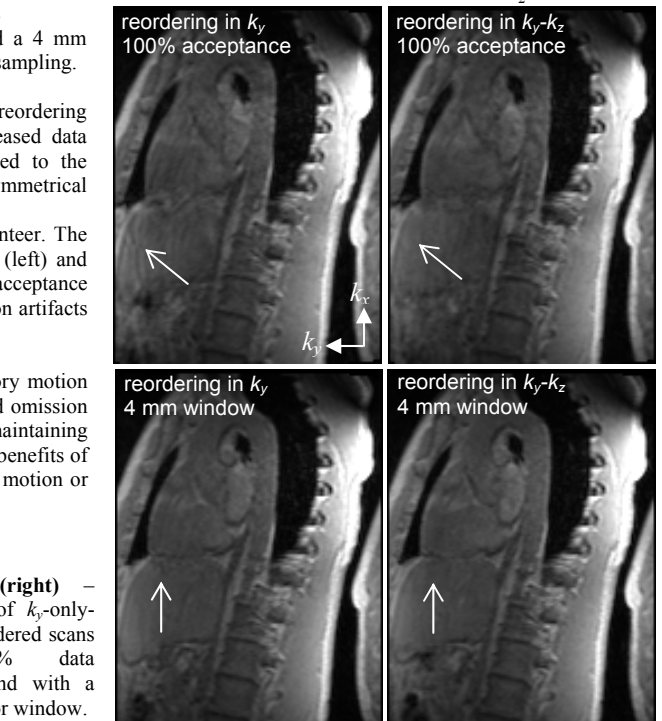
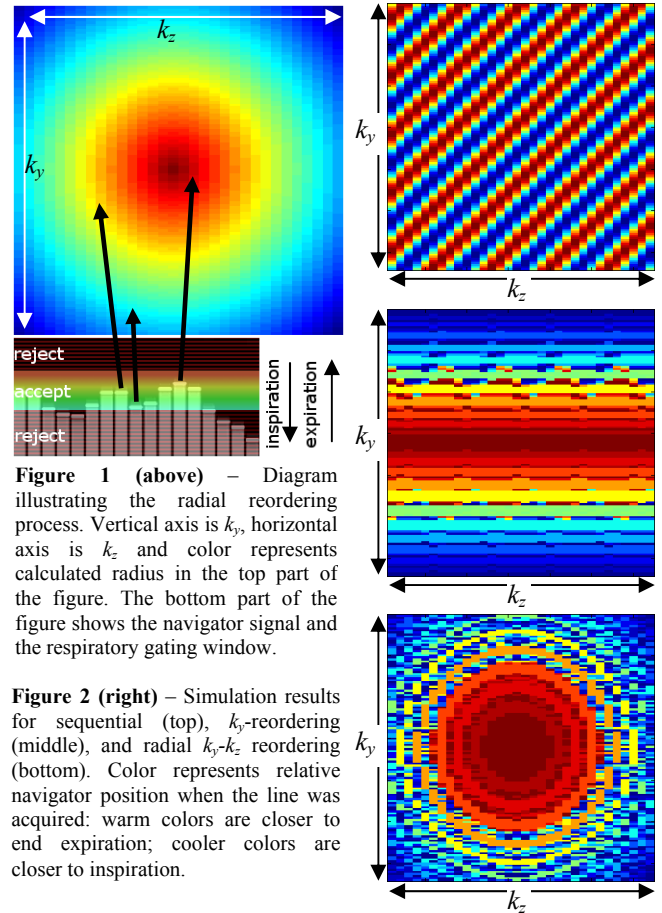


Figure 3 (right) – Comparison of k_y -only- and k_y - k_z -reordered scans with 100% data acceptance and with a 4mm navigator window.