Undersampled Projection Reconstruction Applied to MR Angiography

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Introduction:
In MR angiography, short scan times due to breath-holding or contrast passage make it difficult to acquire adequate spatial resolution. In conventional FT acquisitions, increasing ky resolution proportionally increases scan time. Small FOV FT imaging can be used to quickly acquire high resolution over a limited area (1). If the FOV is reduced, then imaging time is decreased for fixed pixel size. Reduced FOV imaging can also be accomplished using projection reconstruction (PR) (2,3). We have recently shown that for the case of MRA, where vessel signals dominate, the advantages of reduced FOV imaging can be simultaneously realized in a large FOV (4). In PR, spatial resolution is determined by the number of readout samples Nr and not the number of projections Np. Complete angular sampling requires that $Np = \pi/2 \cdot Nr$. As Np is reduced, radial artifacts emanate from each object but spatial resolution remains unchanged and is uniform throughout the large FOV. We have found these artifacts to be acceptable in selected applications. We present results of undersampled PR applied to MRA using both contrast and inflow techniques.

Methods: Projections were acquired as fractional echoes in the kx-ky plane through a 180° range of angles. Partition-encodings in the kz direction are used for 3D imaging. Images were reconstructed with filtered back-projection and homodyne.

Contrast MRA: For contrast-enhanced imaging, we present three approaches. The approaches differ only in the order that k-space data (projections and partition-encodings) are collected.

In the first method, ZIPR (kZ-encodings Inside PRojections) (Fig. 1), all of the partition-encodings are acquired for each projection prior to incrementing the projection angle, and the full data set is repeatedly acquired. The projection angle is incremented sequentially. Multiple time frames can be formed using a sliding temporal window to choose complete sets of projections for reconstruction. This results in azimuthal weighting of kx-ky-space by the contrast. A second method, Interleaved ZIPR, differs in that k-space is filled by skipping angles. The skipped angles are acquired on subsequent passes. In this mode, undersampling is a result of using data only during a temporal window that is shorter than the full acquisition window. We have achieved interleaving in several ways. The example presented here resulted from acquiring multiple sets of projections which are offset by a small angle (5).

In the third method, PRIZE (PRojections Inside kZ-Encodings) (Fig. 1), all of the projections are collected for each sequential partition-encoding. Therefore, contrast-induced artifacts will appear in the slice direction instead of the azimuthal direction as in ZIPR. The center of kz-space can be timed to occur at peak arterial contrast, as in conventional FT MRA to suppress veins.

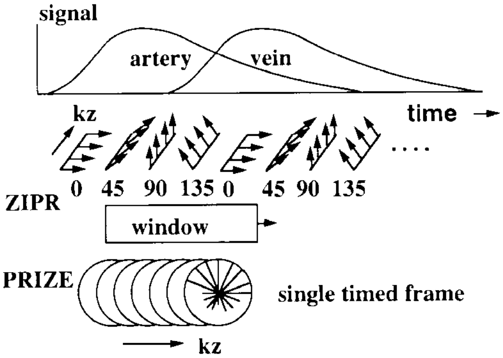

Figure 1: Acquisition orders of projections and kz-encodings for PR contrast-enhanced PRIZE and ZIPR.

Time of flight MRA: FT 3D TOF was compared to PR 3D TOF, using a ramped flip angle and magnetization transfer.

Results: Contrast MRA
Figure 2 shows a contrast-enhanced Interleaved ZIPR study of the abdomen using 512 readout resolution and 256 angles. The projections were divided into 8 sets of 32. The changes in SNR, undersampling artifact and contrast presence when the images are reconstructed with progressively more data are shown in Fig. 2.

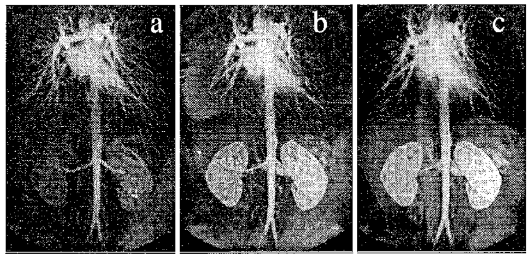

Figure 2: Interleaved ZIPR study of the abdomen reconstructed with (a) 2 sets (64 angles), (b) 3 sets (96 angles), (c) 8 sets. Each set was acquired in 5 seconds. Voxel size = 0.8 x 0.8 x 4.4 mm.

Time of flight MRA: The circle of Willis was imaged with 3D TOF, using both PR and FT acquisitions. Both images in Figure 3 show a sagittal MIP through an axially acquired volume. Slice resolution in PR (Fig. 3b) was increased by a factor of three relative to FT (Fig. 3a) with no increase in scan time.

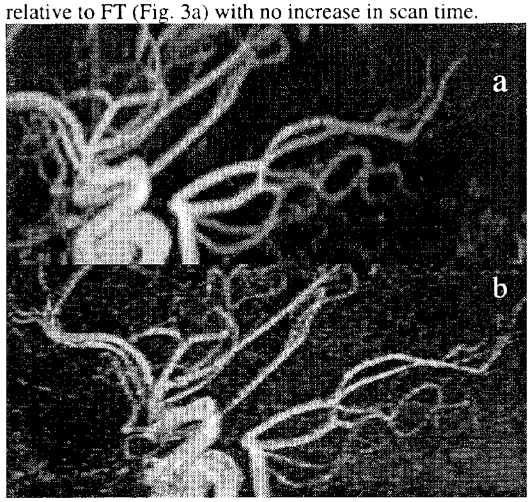

Figure 3. 3D TOF MIPs: (a) FT matrix of 256 (kx) x 192(ky) x 48 (kz) is compared to (b) a PR matrix of 256 (Nr) x 64 (Np) x 128 (kz). Notice the improved resolution in the PR acquisition. FOV and slab thickness are equal in both scans.

Discussion and Conclusions:
The undersampled PR acquisition provides higher resolution per unit time relative to FT. The SNR is accordingly lower, because of smaller voxels. The artifacts are not limiting, even with the serious undersampling shown in Fig. 2. Applied to CE-MRA, the ZIPR methods provides centering of the reconstruction window along the contrast curve, but artifacts are possible from azimuthal contrast weighting. Interleaved ZIPR provides temporal resolution and speed to observe contrast dynamics. PRIZE offers centric kz-encoding to suppress veins. For 3DTOF applications which typically use long scan times, the PR method can be used to provide in-plane resolution equivalent to FT but significantly higher slice resolution. In summary, azimuthally undersampled PR provides a new relationship between resolution and acquisition time in MRA.

1. Fredrickson J. MRM 35, 621(1995) **2.** Scheffler, K, MRM 40, 474 (1998) **3.** Weiss, S, 6th ISMRM 181 (1998) **4.** Peters, D. 6th ISMRM 182(1998) **5.** Rasche, V. MRM 34, 754 (1995).