Undersampled Elliptical Centric View-ordering for Improved Resolution in Contrast-Enhanced MRA

A. J. Madhuranthakam[1], H. H. Hu[1], D. G. Kruger[1], A. V. Barger[1], S. J. Riederer[1]

[1]MR Research Lab, Mayo Clinic College of Medicine, Rochester, MN, United States

Introduction: There has been considerable recent interest in undersampled projection reconstruction (PR) applied to contrast-enhanced MR Angiography (CE-MRA) (1-3). The primary advantage of undersampled PR is its robustness to undersampling artifact when compared to the familiar aliasing artifacts obtained with Cartesian undersampling. However, for a non-time-resolved high quality angiogram without venous contamination, low spatial frequency information is ideally acquired before venous return. With PR every view passes through the center of k-space and venous enhancement is problematic. Even when a temporal filter is used (3), the center of k-space is over-sampled resulting in reduced scan time efficiency. On the other hand, elliptical centric (EC) view ordering has been shown to provide high quality angiograms with limited venous signal even with scan times of 30 sec or longer (4). In this current work, we propose an EC view ordering with a PR type of undersampling applied to the periphery of the ky-kz phase encoding plane for further resolution improvement. Because of the Cartesian sampling, it will be more robust to off-resonance effects.

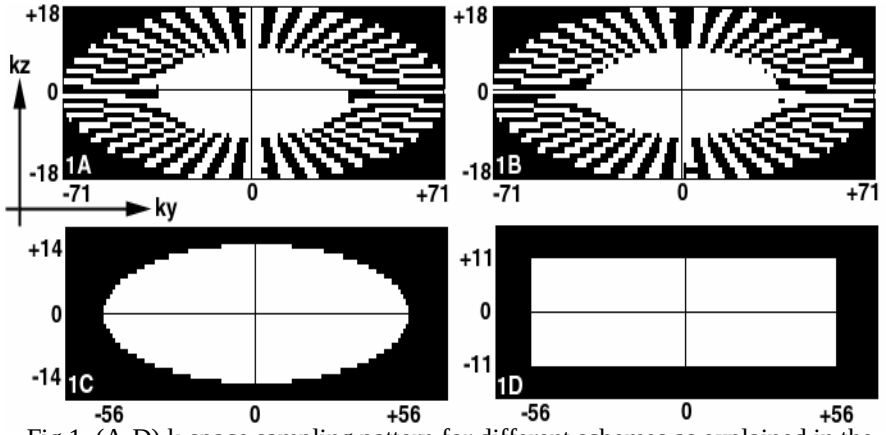

Fig 1. (A-D) k-space sampling pattern for different schemes as explained in the text. Views shown in white are sampled and in black are zero-filled. Note the increased ky and kz sampling in A and B.

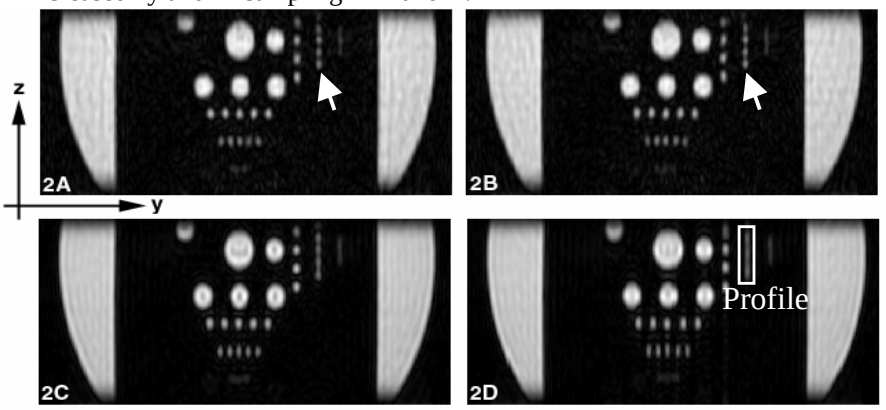

Fig 2. Axial images of a resolution phantom reconstructed from the sampling pattern shown in Fig. 1 respectively.

Methods: The k-space sampling is performed by modifying the view ordering of a standard 3DFT EC acquisition. First, the views in the ky-kz plane are ordered based on their Euclidean distance to the center of k-space. Next, the views are arranged in different angular radial zones within a small angle of about 8^0. At the onset of the acquisition, the view ordering starts from the center of the k-space as in pure EC and progresses to the periphery of the k-space. After sampling ¼ of the total views in the center of ky-kz plane, the outer views are undersampled by sampling the views in every other angular zone. Two different cases of sampling patterns are considered for undersampling.

CASE 1: The center ¼ of the total views in the ky-kz plane is sampled in a pure EC manner. While sampling the outer k-space, views that fall in every other radial zone are sampled, giving an undersampling factor of about 2 in the outer region of k-space. This sampling pattern is shown in Fig. 1A, where the radial zones in the opposite hemispheres of the k-space are symmetrically oriented. At the end of sampling the missing data can be zero-filled or estimated by standard interpolation techniques.

CASE 2: Similar to Case 1, the center ¼ of the ky-kz plane is sampled in a pure EC manner. However, for the upper hemisphere of the outer k-space, views in every other radial zone are sampled while for the lower hemisphere, those views that are anti-symmetrically oriented to the upper hemisphere are sampled. This sampling pattern is shown in Fig. 1B. Prior to reconstruction, the missing data can be zero-filled or estimated by 2D homodyne.

Results: Figure 1 shows the sampling patterns in the ky-kz plane. For comparison, two other sampling patterns are also shown for the same acquisition time (same number of TRs). Fig. 1C shows the views sampled within an ellipse and Fig. 1D shows views within a rectangle without any undersampling. Figure 2A-D show axial images of a resolution phantom that were reformatted from the coronal acquisition, using the sampling patterns of Figs. 1A-D, respectively. For the two undersampling cases (A and B) discussed in this work, the missing data were zero-filled. Note the improved spatial resolution with the undersampling schemes (arrows). Figure 3 shows the line profile across the resolution bar shown in Fig. 2D clearly demonstrating the superiority of the two undersampled methods.

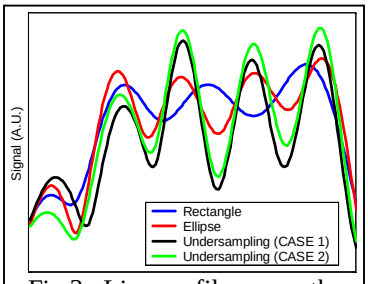

Fig 3. Line profile across the spatial resolution bar identified in Fig. 2D

Discussion: We have demonstrated an EC view ordering with a PR type of sampling applied to the periphery of the phase encoding plane. This sampling pattern traverses the center of k-space as in standard EC but for the same scan time progresses farther in k-space due to undersampling. The initial implementation was targeted towards improved Z resolution, and this was verified in the experimental results. This type of sampling could be readily implemented for CE-MRA.

References: 1) Peters DC, Magn Reson Med 43: 91-101 (2000) 2) Vigen KK, Magn Reson Med 43: 170-176 (2000)
3) Barger AV, Magn Reson Med 48: 297-305 (2002) 4) Wilman AH, Radiology 205: 137-146 (1997)