Liver MR Image Quality: Reducing Anisotropic Noise in Zero-filled Spin-warp Imaging

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Introduction Lesion detection in dynamic contrast enhanced (DCE) liver imaging relies heavily on the uniform appearance of background normal liver parenchyma. With recent improvement of DCE acquisition techniques, previously unnoticed subtleties in image homogeneity have become relevant. One such subtlety is the distracting appearance of anisotropic noise in interpolated (zero-filled) reconstructions. In low signal-to-noise ratio (SNR) imaging, the anisotropic noise appears as a "cross-hatch" noise pattern resulting from a preponderance of image noise power in the diagonal directions. This study investigates a possible origin of the anisotropic noise distribution, and proposes methods to remove the "cross-hatch" noise pattern during reconstruction.

Method In spin-warp imaging, a rectangular portion of k-space is sampled. While a circle in 2D k-space represents isotropic frequency response and noise distribution, spin-warp imaging additionally acquires the corners of k-space. However, because of rectangular image voxel dimensions, the diagonal high spatial frequencies represented by the corners of k-space are better depicted in images after zero-filling (Fig 1, bottom row)[1]. A Matlab (The Mathworks, Bellerica, MA, USA) model was developed to illustrate the effects of anisotropic noise with and without zero-filling.

Two reconstruction methods were implemented to remove the "cross-hatch" noise pattern and were applied to a fully-sampled, SNR-limited, spin-warp, axial liver acquisition with equivalent x and y spatial resolution. The first reconstruction removes the corners of k-space by simply applying a circular apodization filter with radius equal to the maximum acquired x and y spatial frequency (k_{xmax}) (Fig 2, column 3). The second reconstruction applies a circular filter of radius=2 k_{xmax}/sqrt(π) such that the k-space area remains constant (Fig 2, column 4). Unsampled areas of the circle are padded with Gaussian noise. This selection minimally clips the corners of k-space, while providing isotropic noise distribution and maintaining the noise power in k-space.

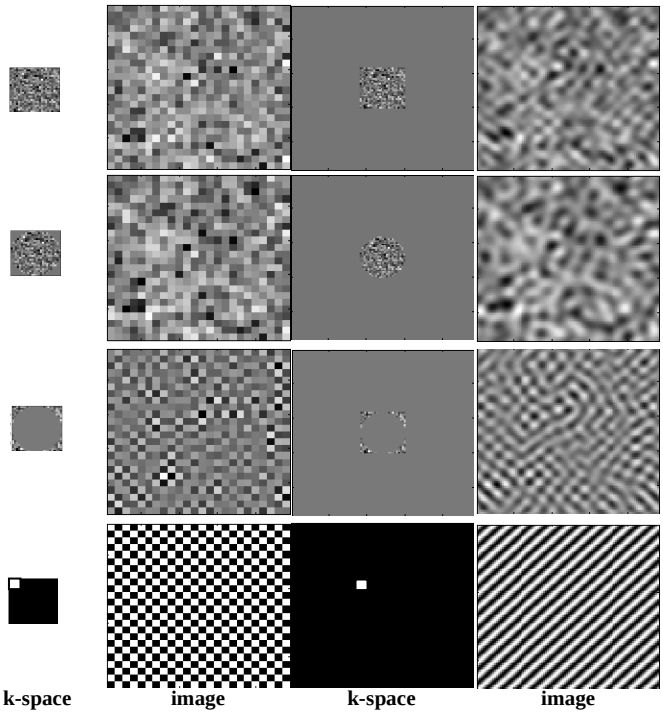

Fig 1. Rows top to bottom: full k-space, center k-space, corner k-space, and zero-fill illustration. Column 1 and 2 are without zero-filling. Column 3 and 4 are with zero-filling. "Illustration" shows corners of k-space contribute more after zero-filling. Equivalent effect for corner of k-space noise (column 4, row 1 and 3).

Results The origin and appearance of anisotropic noise is illustrated in Fig 1. Anisotropic noise (Fig 1 column 4, row 3) originates from the corners of k-space and is realized in image space after zero-filling. Reconstructions are presented in Fig 2. Both circular filters remove the "cross-hatch" noise pattern observed in the reconstruction of rectangular k-space. The smaller radius circular filter (column 3) increases image SNR but reduces image resolution in the diagonal directions. The larger radius circular filter (column 4) closely maintains image SNR and minimally reduces diagonal resolution.

Discussion While often subtle, the appearance of anisotropic noise in DCE liver imaging is distracting and may impair diagnosis. This study illustrates a possible origin of such noise and shows its dependence on zero-filling, a procedure typically felt only to enhance the appearance/smoothness of 3D MR images. Improvements to reconstruction algorithms must consider image resolution as well as the impact on noise appearance and SNR to optimally achieve diagnostic efficacy. The reconstruction algorithms presented here minimally affect SNR and resolution while removing anisotropic noise. Further study is required to assess improvements in diagnostic efficacy.

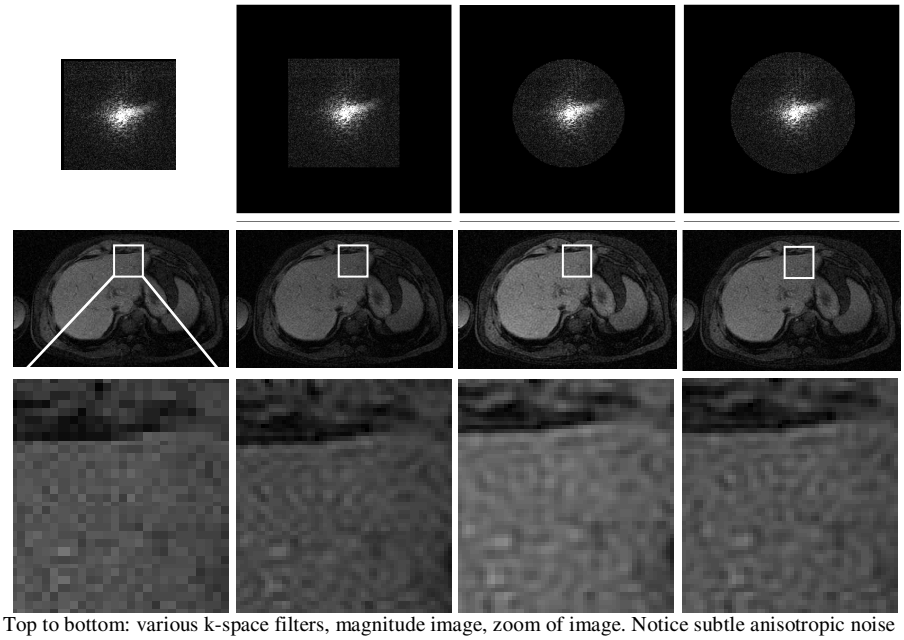

Fig 2. Top to bottom: various k-space filters, magnitude image, zoom of image. Notice subtle anisotropic noise appearance in zero-filled, square k-space reconstruction (column 2), and absence of such in other reconstructions.

References

1.) MA Bernstein, SB Fain, SJ Reiderer, J Magn Reson Imaging 14:270, 2001.