Evaluation of Sparse k-space sampling schemes for fast cardiac MRI using compressed sensing reconstruction technique

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Target Audience: This study is relevant to investigators or radiologists who are interested in the optimization of sparse sampling in k-space and reconstruction methodologies for fast MRI.

Purpose: Sparse acquisition MRI has been shown to be very promising in decreasing scan times while achieving clinically diagnostic image. In many published sparse acquisition schemes [1-3], multiple central k-space lines are acquired with the assumption that more lines in the center of k-space will result in better reconstructed image quality due to the high contrast information. Though this belief seems plausible, to the knowledge of the authors, no study or simulation has been performed to verify this practice. The purpose of this study is to determine how the number of central k-space lines affects the overall reconstructed image quality in sparse sampling acquisitions using the compressed sensing reconstruction method [4].

Methods: A fully sampled axial cardiac aortic scan for a healthy male volunteer was acquired on a Philips 3T system (R3.2.1 software). The cardiac scan had the following parameters: 0.8 x 0.8mm in plane resolution, 6 mm slice thickness, TE/TR = 5.5/15 ms, FA = 10 degrees, VENC = 200 cm/s, and 35 cardiac phases. With the compressed sensing reconstruction method through the use of Wavlets, custom software written in IDL was used to simulate different k-space sampling percentages: i.e., 100, 90, 80, 70, 60, 50, 45, 43, 40, 30, and 25% random sampling in k-space with varying number of central k-space lines: e.g., 1, 3, 5, 8, 13, 18, and 26 central lines. The quality of reconstructed images was assessed by calculating percentage difference between original and reconstructed images as follows: $\left(\sqrt{\sum [I_o(x,y) - I_r(x,y)]^2}\right) / \left(\sqrt{\sum I_o(x,y)^2}\right) \times 100\ [\%]$, where $I_o(x,y)$ is the original fully sampled image and $I_r(x,y)$ is a reconstructed sparsely sampled image.

Results: Reconstructed images with at least 3 central k-space lines show background ghosts below 43% random sampling in k-space (Fig.1). Decreasing k-space sampling percentage induces increasing image quality difference and reconstruction error (Fig.2). More than 60% random k-space sampling indicates that there is no difference in image quality between original and reconstructed images irrespective of varying number of central k-space lines. Below 43% k-space random sampling, the percentage image quality difference is greater than 10% for different number of central k-space lines except one central k-space line.

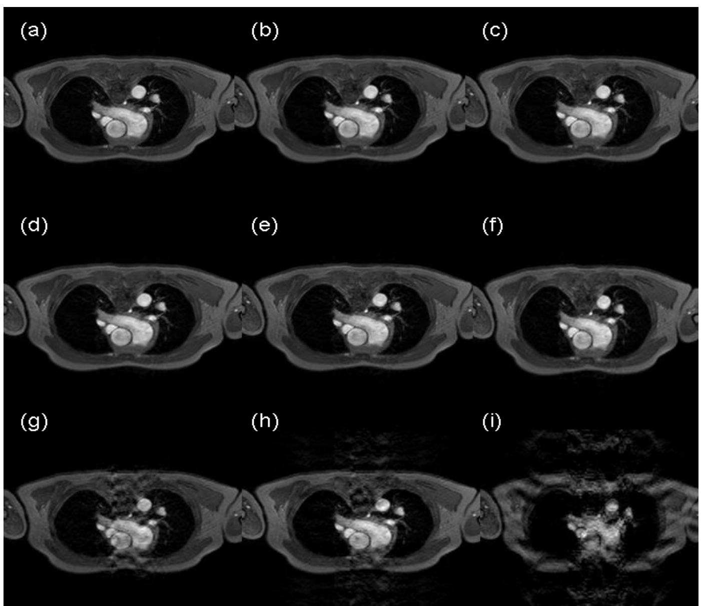

Fig.1 Original image (a) and reconstructed images with 90%(b), 70% (c), 60%(d), 50%(e), 43%(f), 40%(g), 30%(h), and 25%(i) random sampling in k-space with 3 central k-space lines.

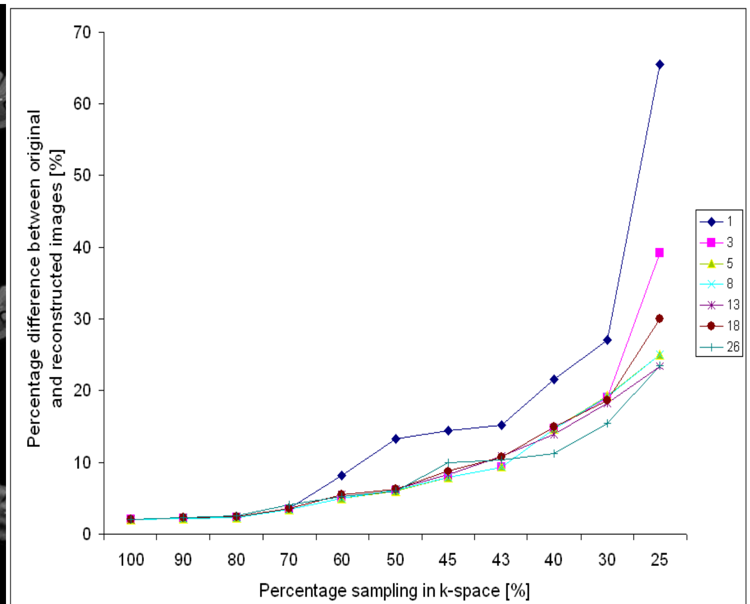

Fig.2 Scatter plot of percentage difference between original and reconstructed images vs. random sampling percentage in k-space with different number of central k-space lines: 1, 3, 5, 8, 13, 18, and 26.

Discussion: Using compressed sensing reconstruction technique, at least 3 central lines and 45% random sampling in k-space appears to take advantage of reducing scan time without changing image quality. At least 60% random k-space sampling is necessary to obtain comparable reconstructed image quality, compared to original images.

Conclusion: This study suggests that sparse k-space sampling schemes with compressed sensing reconstruction technique play a significant role in fast cardiac MRI. Furthermore, we have shown how the number of central k-space lines affects sparsely sampled image quality.

References: [1] Sodickson et al, MRM, 1997, 38(4):591-603; [2] Larkman et al, Phys Med Biol, 2007, 52(7):R15-55; [3] Lustig et al, 2007, 58(6):1182-95, 2007 ; [4] Kim et al, IEEE Topics in Signal processing, 2007, 1(4)606-17