Dynamic Contrast-Enhanced Breast MRI using Flexible Radial Undersampling with Compressed Sensing Reconstruction

R. W. Chan[1], E. A. Ramsay[2], E. Y. Cheung[3], and D. B. Plewes[1,2]

[1]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada, [2]Imaging Research, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada, [3]University of Waterloo, Waterloo, Ontario, Canada

Introduction: Flexible radial imaging allows multiple image sets, each having a different spatiotemporal balance, to be retrospectively reconstructed from the same dataset [1,2]. One of the applications that may benefit from this flexibility is dynamic contrast-enhanced breast imaging, in which the optimal spatiotemporal balance for image diagnosis is unknown. Images from radial undersampling have good overall image contrast at high temporal resolutions, but they suffer from undersampling streak artifacts that degrade image quality. Compressed sensing (CS) L1-penalized reconstruction has been shown to reduce such streak artifacts [3-5] by enforcing sparsity in the image. Here, we implement flexible golden-angle radial sampling [1,2] on a healthy human volunteer, and reconstruct images with CS over a range of spatiotemporal resolutions. We compare the golden-angle method with other sampling schemes (bit-reversed and random sampling), and assess the ability of CS reconstruction to reduce streak artifacts in each sampling method.

Methods: A healthy volunteer was imaged unilaterally with dedicated breast coils (TE/TR/flip= 3.5ms/10ms/30deg, FOV=20cm, BW=31.25kHz, 4mm-thick slices) and with the following in-plane radial sampling schemes, implemented in a 3D stack-of-stars sequence. Each kx-ky plane consisted of 512 spokes: i) **Golden-angle**: 2D radial projections are successively are incremented by the golden angle ($\sqrt{5}-1)/2 \cdot 180° \approx 111.25°$ [1-2]. No subset is perfectly evenly-spaced, but spokes are relatively well-distributed for every resolution. ii) **Bit-reversed**: This method generates evenly-spaced projections only at 2^n spokes, where n is an integer. For other resolutions, the spokes are unevenly distributed. iii) **Random**: Projections having random angles between 0 and 180° were used for sampling.

Image Reconstruction: For a range of spoke-numbers and for each sampling scheme, images were reconstructed with both Fourier and CS reconstruction. In CS reconstruction, an L1-penalized non-linear iterative reconstruction algorithm (Lustig's "SparseMRI" Matlab code [5], implemented on graphical processing units for faster processing) was used to minimize the following cost function: $C(x) = \|F \cdot W^H \cdot x - y\|^2 + \lambda_1 \cdot |x|_1 + \lambda \cdot TV \cdot (W^H \cdot x)$, where x is the wavelet image, y is the k-space data, W is the 2D wavelet transform, TV is the total variation operator, F is the Fourier operator, and superscript H denotes the adjoint operator. The regularization parameters used were λ_1=0.1 and λ_2=0.1.

For each spatiotemporal resolution (eg. 27 spokes), CS images were reconstructed from successive time-groups (eg. using spokes 1-27, 28-54…etc) up to 512 projections. An *RMS error* was calculated between each CS image and the fully-sampled Fourier image satisfying the Nyquist criterion. The *standard deviation (of the RMS errors)* was computed over time-groups from the same spatiotemporal resolution.

Results: For a range of spoke numbers and for each sampling scheme, Figure 1 shows a plot of the RMS errors in the CS images, as well as their standard deviations across time-groups (denoted by error bars). Except for certain projections (ie. 16 and 32 projections, where bit-reversed sampling gives evenly-spaced spoke-sets), golden-angle sampling has a lower RMS error overall. Figure 2 shows Fourier (a-c) and CS (e-g) images reconstructed from an arbitrary 27 projections, as well as the fully-sampled truth (d, h). The corresponding RMS errors for the CS images (2e-g) are 6.86, 5.51 and 4.98 for random, bit-reversed and golden angle sampling, respectively (also plotted in Figure 1, shown by x's).

Fig 1.

Fig 2.

Discussion & Conclusions

In general, CS-reconstructed images using golden-angle radial sampling have lower RMS errors compared to bit-reversed and random sampling. Bit-reversed sampling performs better only when the set of spokes is evenly-spaced (16 and 32 projections), while golden-angle sampling results in improved image quality for most other resolutions. Golden-angle sampling results in lower standard deviations overall when all the time-groups are considered. Random radial sampling performed the worst over the entire range of temporal resolutions, with relatively large standard deviations.

References [1] Winkelmann, S. IEEE Trans Med Imaging 2007; 26:68-76. [2] Song HK, et al. Proc. ISMRM 2006, Seattle, p.3364. [3] Donoho D, IEEE Tran Info Theo 2006 52:1209-1306. [4] Candes E et al. IEEE Tran Info Theo 2006 52:489-509. [5] Lustig M et al. Magn Res Med 2007 58:1182-1195.