Time-Resolved Fetal Cardiac MRI Using Compressed Sensing and Metric Optimized Gating

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Introduction: Imaging the fetal heart with MRI typically suffers from artifact due to non-gated cardiac motion and gross fetal motion. Using Metric Optimized Gating (MOG) it has been shown that time-resolved images of the fetal heart and vessels can be reconstructed from non-gated data [1]. Still, the possibility of gross fetal motion during lengthy acquisitions remains a limiting factor. Compressed Sensing (CS) allows rapid cardiac MR imaging by undersampling kspace, however integration with MOG is challenging because both reconstruction methods aim to reduce two competing sources of artifact (cardiac motion and undersampling) [1-3]. In this work, we outline an approach that integrates CS with MOG (CS-MOG) and demonstrate their combined ability to reconstruct undersampled fetal cardiac MR data.

Theory: CS-MOG data are acquired using a constrained pseudo-random undersampling scheme [3]. In the absence of an electrocardiogram (ECG) signal for gating, the cardiac phase of each segment is retrospectively determined according to a hypothetical model of the heart rate. Data are binned according to cardiac phase and an intermediate set of fully sampled images are reconstructed through temporal interpolation avoiding artifact from random undersampling at the cost of temporal filtering. An image metric (entropy) is used to quantify artifact from incorrect binning and the hypothetical heart rate model is iteratively adjusted until the cardiac phase of each segment is determined. The data are once again binned but not interpolated, and a CS reconstruction based on iterative soft thresh-holding is used to fill in the missing data [2].

Methods: To evaluate CS-MOG at several reduction factors, a numerical simulation of a Cartesian CINE cardiac MRI acquisition was created using the MRXCAT model in Matlab (MathWorks, USA) [4]. The numerical simulation incorporated realistic ventricular motion, fetal heart-rate variability and image noise. Simulated MRI acquisitions with prospective undersampling were reconstructed using CS-MOG and compared to CS reconstructions using the known simulated heart rates (CS-ECG). Quantitative comparison between reconstruction methods was evaluated by the root-mean-square error (RMSE) relative to fully sampled data [3]. To demonstrate feasibility in the fetal population, fully sampled fetal data were acquired in a normal human fetal subject (35 weeks gestational age) and retrospectively undersampled offline.

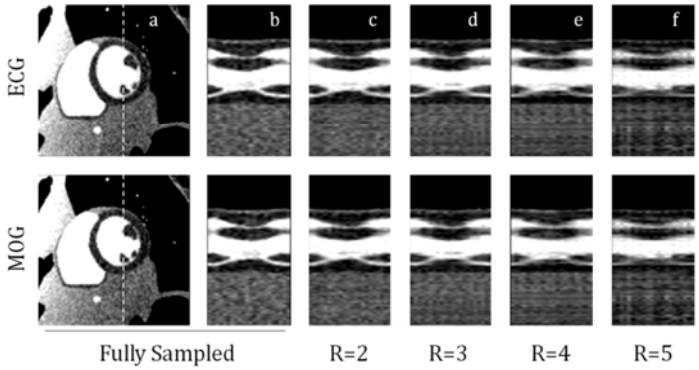

Figure 1 Numerical simulation results comparing (top) CS-ECG and (bottom) CS-MOG reconstructions of (a) fully sampled data and (b-f) temporal profiles for increasing undersampled data (R = 2:5).

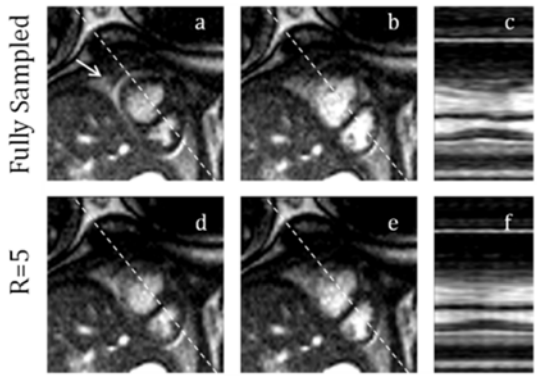

Figure 2 Reconstructions of fully sampled and retrospectively undersampled fetal data. (a, d), End-systole, (b, e) end-diastole, and (c, f) temporal profiles indicated by the dashed lines in figures (a, b,

Results & Discussion: Figure 1 displays the results of a numerical simulation of prospectively undersampled CINE cardiac acquisitions for several reduction factors. The image quality of CS-MOG reconstructions is comparable to CS-ECG reconstructions, as are the RMSE values shown in Figure 3. Figure 2 shows the results of fully sampled and retrospectively undersampled fetal data. With a reduction factor of five, visibility of the thin rim of pericardial fluid denoted by an arrow in Figure 2a is blurred due to residual artifact from the CS algorithm however radial contraction of the ventricles remains well defined thus demonstrating the feasibility of this method for reconstructing undersampled non-gated fetal cardiac MR data. With this approach, time-resolved high resolution images of the fetal heart can be acquired in considerably less time.

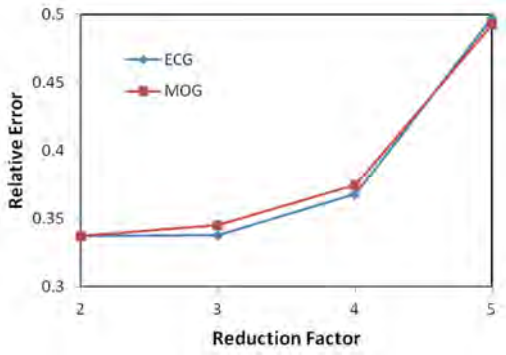

Figure 3 Comparison of CS-ECG and CS-MOG RMSE values for increasing reduction factors.

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[3] Gamper U *et al* MRM 2008;59:365–373
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