Metric Optimized Gating for Fetal Cardiac Imaging

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Introduction: In fetal cardiac MR imaging, conventional ECG gating is not possible. Metric optimized gating (MOG) is a metric based retrospective reconstruction technique for cine MR imaging of the fetal heart and blood flow [1]. Previously, MOG has been applied to PC-MRI data to measure fetal blood flow. Here, we present a modified version of MOG for fetal myocardial imaging, and investigate the effects of optimization parameters on image quality through numerical simulation and *in vivo* validation.

Theory: MOG data are acquired using conventional cine pulse sequences, but in place of the physiological ECG trigger, a synthetic periodic trigger is used for data acquisition. The period of this trigger is chosen to be longer than the longest heart cycle of the subject, which ensures that each line of k-space is acquired for each cardiac phase. The oversampled data are then retrospectively sorted and reconstructed using a parameterized heart rate model. This model is iteratively adjusted until an image metric value is optimized. In MOG for fetal blood flow, the entropy in time was minimized. We have observed that the entropy in space is minimized for optimal anatomical image quality [2].

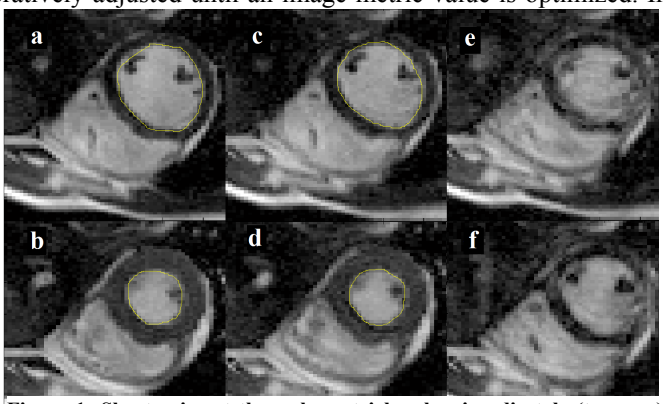

Figure 1: Short-axis cut through ventricles showing diastole (top row) and systole (bottom row) for (a-b) ECG gated; (c-d) MOG and (e-f) misgated images.

Methods: *In vivo* validation was performed in a healthy adult volunteer. Data were acquired first with conventional ECG gating and subsequently with oversampling for MOG reconstruction. Cine SSFP data were acquired with TR/TE = 2.7/1.2, flip angle = 70°, voxel size = 2x2x5 mm^3, 8 views-per-segment. Scan times were 20s and 25s for gated and oversampled measurements, respectively. Data were reconstructed offline using the MOG method coded in MATLAB (The Mathworks, Natick USA). Ejection fraction estimates were performed using ImageJ (NIH, USA).

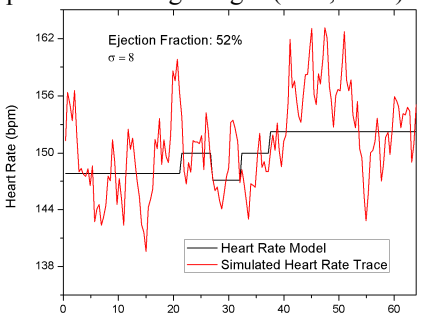

Figure 2: Simulated heart rate trace and corresponding heart rate model

A numerical model simulating a short-axis cut through the ventricles was used to evaluate the modified MOG method. This simulation incorporated realistic ventricular motion and heart-rate variability [3]. Simulated images were reconstructed using MOG and compared to reconstructions using the known simulated heart rates (gated). For each set of images, the left ventricle ejection fraction was calculated as a quantitative measure of reconstruction accuracy.

For both simulated and *in vivo* data, a five parameter heart rate model was chosen for optimization. Model parameters (R-R times) were distributed throughout the scan and weighted by their proximity to the center of k-space [2, 4]. Parameters were individually adjusted in succession and then refined in combination over a smaller range. This is shown in Figure 2 for a simulated trace.

Results & Discussions: Figure 1 shows short-axis views of an adult heart. These images represent reconstructions using ECG gating, MOG and for comparison, misgating. Visually, the MOG reconstructions compare well with the ECG gated images. Note that for the misgated reconstruction, there is no clear difference between diastolic and systolic images. Furthermore, adult ejection fraction estimates for each reconstruction agree within error (MOG: 53±3, ECG: 56±3). The *in vivo* results represent the average and standard deviation of 5 measurements performed in ImageJ.

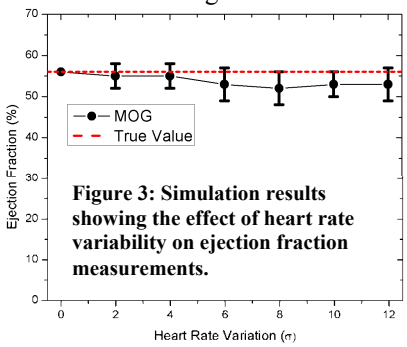

Figure 3: Simulation results showing the effect of heart rate variability on ejection fraction measurements.

Figure 3 shows the effects of heart rate variability (σ) on simulated ejection fraction measurements, where σ is the standard deviation of the beat-to-beat difference in heart-cycle duration [3]. Each data point represents the mean and standard deviation of 100 simulation runs at each value of σ. The simulated ejection fractions compare with the true value within error; however, within the typical fetal σ range of 6-10, ejection fractions were increasingly underestimated. A decrease in entropy was observed in both simulated and *in vivo* data using an increasingly higher-order heart rate model. Further increasing the complexity of this model may lead to improved accuracy for high σ, albeit at the expense of increased computational time. In conclusion, we have demonstrated the feasibility of MOG for MR imaging of the fetal heart.

[1] Jansz MJ *et al* MRM 2010;64:1304–1314, [2] Atkinson D *et al* IEEE Trans Med Imaging 1997;16(6):903-910, [3] Ortiz R *et al* J Med Eng Technol 2002;26(1):39-45, [4] McGee, K P *et al* MRM 200;43(4):583-588