Dynamic Imaging of the Fetal Heart Using Metric Optimized Gating

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Introduction: In fetal cardiac MR imaging, an ECG gating signal is unavailable. Metric optimized gating (MOG) is a metric based retrospective reconstruction technique for cine MR imaging without conventional gating [1]. In this work, MOG is developed and validated for cine imaging of the fetal heart. Evaluation of the MOG technique is performed by comparing MOG and ECG reconstructions of the same adult volunteer data. Cine MR images of the human fetal heart are presented and the performance of MOG applied to fetal data is evaluated through error analysis.

Theory: MOG data are acquired using conventional cine pulse sequences, but in place of the physiological ECG trigger, a synthetic periodic trigger is used. 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. Upon collecting synthetically triggered data, a hypothetical gating waveform is created that spans the period of image acquisition. Images are reconstructed, artifact from cardiac motion is quantified using a metric for image quality (entropy), and the relative timings of the hypothetical triggers are adjusted. The process is repeated until the image metric is optimized, and the optimum set of cine images are output [2].

Methods: *In vivo* validation was performed in healthy adult volunteers. Short axis images of the heart were acquired on a 3.0T MRI scanner (TRIO, Siemens Healthcare – Germany) using a multi-channel cardiac coil. Three sampling strategies were performed: Cartesian sampling without parallel imaging, Cartesian sampling with GRAPPA, and radial sampling without parallel imaging (voxel Size = 2mm x 2 mm x 8 mm, temporal resolution = 46 ms). For each scan, data were acquired under breath-hold and the ECG waveform was recorded for subsequent qualitative and quantitative comparison between ECG and MOG reconstructions. Quantitative evaluation was performed using two error analysis methods. First, the experimental error in MOG reconstructions was calculated from the standard-deviation of the difference between ECG trigger times and the hypothetical trigger times provided by MOG. Second, the theoretical errors in the MOG trigger times were calculated based on the uncertainty in the minimum metric value [3]. Short axis images of the fetal heart were acquired in a normal fetal subject (35 weeks gestational age). Fetal scans were performed on a 1.5T MRI clinical scanner (Avanto, Siemens Healthcare – Germany) using a multi-channel abdominal coil (voxel Size = 1.3 mm x 1.3 mm x 4 mm, temporal resolution = 25 ms). In the absence of an ECG gating signal for comparison, qualitative assessment of image quality was performed by an expert radiologist and quantitative evaluation of MOG performance was assessed by the theoretical error in the MOG trigger times.

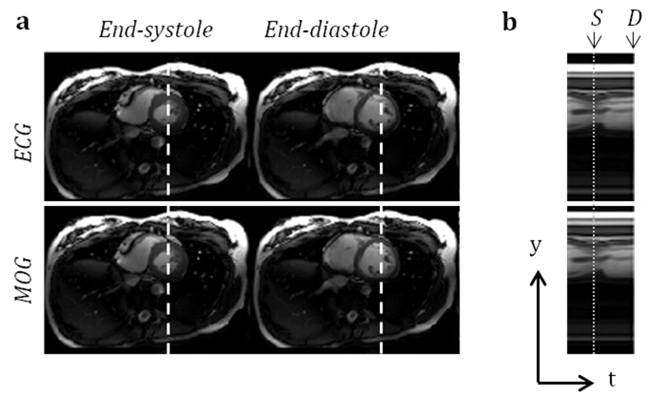

Figure 1: Comparison of ECG (top) and MOG (bottom) adult volunteer reconstructions: a) Cartesian data without parallel imaging showing a short-axis cut through the ventricles at end-systole (S) and end-diastole (D). b) Plot of the temporal evolution of the signal along the white dashed line in (a).

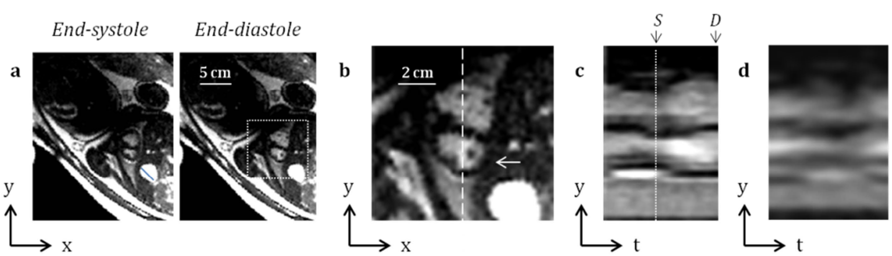

Figure 2: MOG reconstructions of a healthy human fetal heart. (a) A short axis view at the mid ventricular level is shown at end-systole (S) and end-diastole (D). (b) Magnified end diastolic image from (a). (c) Plot of signal intensity versus time for the dashed line in (b). (d) Same plot as (c) before application of MOG, showing obscured radial contraction due to artifact from cardiac motion.

Results & Discussions: Figure 1 shows short-axis views of a representative adult volunteer. Visually, the MOG reconstructions compare well with the ECG gated images. The mean experimental error across each sampling strategy was ± 7 and the theoretical errors in MOG trigger times had a standard deviation of 7 ms and ranged from ±2 ms to ±16 ms. Figure 2 shows example cine MR images of a human fetal heart. The cross-sections of the antero-lateral and postero-medial papillary muscles are visible in the left ventricle (arrow in Figure 2b), demonstrating the ability of MOG to resolve small dynamic structures. The M-mode display shown in Figure 2c demonstrates the dynamic heart motion reconstructed using MOG. Radial contraction and relaxation of the fetal ventricles is well represented, allowing assessment of ventricular function using this approach. The theoretical errors in the optimized fetal trigger times had a standard deviation of 13 and ranged from ± 3 ms to ± 34 ms). In conclusion, the accuracy of a novel gating approach was evaluated in healthy adult volunteers and in a fetal subject. With this method, gated high resolution dynamic images of the human fetal heart were acquired using a conventional cine MRI acquisition.

[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] Bevington P, Robinson DK. McGraw-Hill; 1994.