

Metric Optimized Gating for Fetal Cardiac MR Imaging

M. S. Jansz^{1,2}, M. Seed³, J. F. van Amerom^{1,2}, S. J. Yoo^{3,4}, and C. K. Macgowan^{1,2}

¹Medical Biophysics, University of Toronto and Hospital for Sick Children, Toronto, Ontario, Canada, ²Medical Imaging, University of Toronto and Hospital for Sick Children, Toronto, Ontario, Canada, ³Pediatric Cardiology, University of Toronto and Hospital for Sick Children, Toronto, Ontario, Canada, ⁴Dignostic Imaging, University of Toronto and Hospital for Sick Children, Toronto, Ontario, Canada

Introduction: Cardiac gating is usually accomplished with ECG electrodes attached to the chest; however, this is not possible *in utero* for fetal cardiac MR imaging. Self-gating techniques have been proposed for this application, but generally require specialized pulse sequences. We propose a new retrospective “gating” technique for conventional data acquisitions that is based on image metric optimization. We demonstrate its feasibility through simulations and successful *in vivo* application.

Theory: Metric optimized gating uses an image metric to quantify and correct for artifact resulting from incorrect gating. The data acquisition is oversampled, meaning that each line of k-space is acquired repeatedly for a period longer than a cardiac cycle. This ensures that the data set contains every line at every cardiac phase—guaranteeing the existence of an exact reconstruction. A set of hypothetical triggers are then used to retrospectively sort the data with respect to cardiac phase. The triggers are distributed throughout the scan according to a heart rate model, and their positions are iteratively adjusted. The best reconstruction is determined by optimizing the image metric over the space of possible trigger times.

We have identified two metrics that are able to detect misgating artifacts in phase-contrast images. First, the image gradient provides a sensitive measure of the smearing of the dynamic components of a vessel in the phase-encoding direction [1,2]. Second, the entropy in time, evaluated on a pixel-by-pixel basis, provides a robust measure of the loss of pulsatility [$(V_{\max} - V_{\min})/V_{\text{mean}}$] in the flow due to misgating.

Methods: Fetal cardiac data were acquired using a conventional phase-contrast gradient echo sequence with flip angle = 30°, voxel size = 1.25x1.25x5 mm³, TE/TR = 2.9/6.6ms, and VENC = 150cm/s. A relatively large FOV (36x24 cm²) was necessary to prevent wrapping of the mother’s abdominal wall. Additionally, positive and negative phase encodes were alternated and every 4 lines of k-space were interleaved to shorten the scan, making the effective temporal resolution 52.6ms. Ten phases were acquired, irrespective of the fetal heart rate, so each line of k-space was acquired repeatedly for 526ms. This ensured that the data was sufficiently oversampled, provided the fetal heart rate remained above 115bpm. The scan time was 41s, but the use of parallel imaging and aggressive FOV prescription can potentially reduce this to a breath-hold. The optimization program was coded in MATLAB (The Mathworks, Natick USA) and ran on the order of 1 minute. A simulation of a small vessel with pulsatile flow was used to study the effects of heart rate variability, waveform shape, and inflow effects on the reconstruction process.

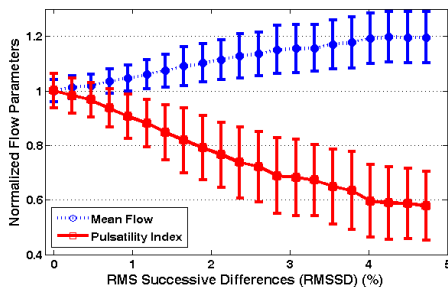


Figure 2: Simulation results demonstrating the effect of heart rate variability. Each data point shows the mean and standard deviation of 400 simulation runs with SNR = 75 and randomized heart rate variation with the given RMSSD.

Results & Conclusions: Figure 1 shows the data extraction process for an *in vivo* fetal measurement with a constant heart rate model (i.e. a one-parameter search). Frame A depicts the metric landscape, showing a clear optimum near 140 bpm, frame B shows the final reconstructed images corresponding to this optimum, and frame C shows the clinically-relevant flow measurement extracted from these images.

Figure 2 shows the simulation results demonstrating the effects of increasing heart rate variability. The RMS Successive Differences (RMSSD) denotes the root-mean-square of the beat-to-beat differences in the heart rate, expressed as a percent of the baseline heart rate. Typical fetal heart rate variation has an RMSSD in the range of 0.5-2.0% [3], and it is apparent that the flow pattern is well preserved within this range.

Given the scan length and typical fetal heart rate variation, a one-parameter model was found to provide reasonably short search times and sufficient flexibility to account for heart rate variability. Additional degrees-of-freedom have been tested but were not found to appreciably improve the value of the metric optimum. In conclusion, we have demonstrated that metric optimized gating can reconstruct oversampled fetal cardiac MR data acquired with conventional sequences.

[1] McGee KP, et al. JMRI 2000; 11:174-81, [2] Xiang QS and Henkelman RM. MRM 1993; 29:422-8, [3] Wakai RT. Exp Neurol 2004; 190 (1):S65-71

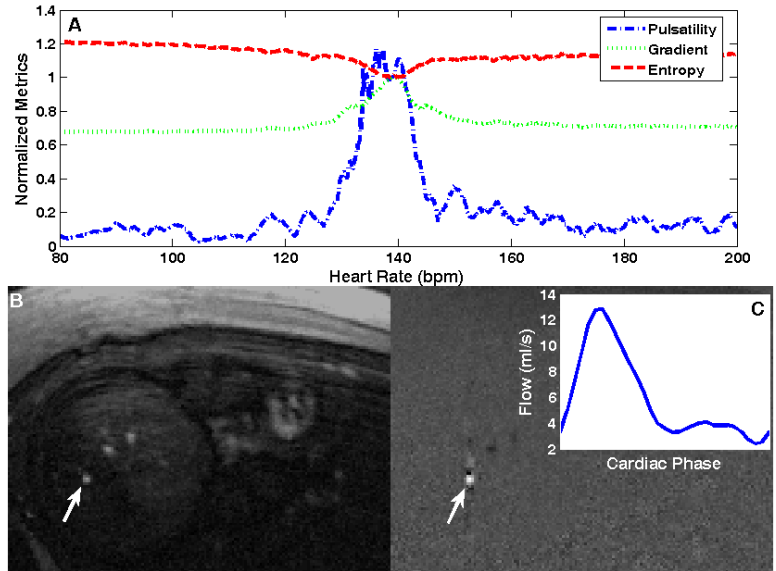


Figure 1: (A) The metric landscape across the one-parameter search. The gradient and entropy were optimized; the pulsatility provides a surrogate marker of gating accuracy. (B) A representative still-frame from the set of optimized images. 40% of the FOV is shown and the arrows indicate the location of the fetal descending aorta (DAo). (C) The flow pattern extracted from DAo in the optimized images.