HASTE imaging with externally optimized skewed saturation pulses for fetal imaging at 3T - initial results

Borjan Gagoski[1], Cornelius Eichner[2], Mukund Balasubramanian[3], Himanshu Bhat[4], Kawin Setsompop[2], and Patricia Ellen Grant[1]

[1]Fetal-Neonatal Neuroimaging & Developmental Science Center, Boston Children's Hospital, Harvard Medical School, Boston, MA, United States, [2]A.A. Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital, Charlestown, MA, United States, [3]Department of Radiology, Boston Children's Hospital, Harvard Medical School, Boston, MA, United States, [4]Siemens Healthcare, Charlestown, MA, United States

Target audience: Fetal neuroradiologists and clinicians; MR physicists and researchers interested in fetal imaging.

Introduction: Fetal magnetic resonance imaging (MRI) has become standard of care for further evaluation of anomalies detected by ultrasound. While 1.5T has been the typical platform for fetal imaging at most institutions, our site has recently started clinical fetal imaging at 3T, thereby exploiting the SNR gains of the stronger field. Nevertheless, the unpredictable motion of the fetus still prevails and therefore fast single-shot encoding techniques, such as Half-Fourier-Acquisition Single-Shot Turbo-Spin-Echo (HASTE), remain the "work-horse" sequence for fetal imaging at 3T. However, even with HASTE imaging using in-plane acceleration factors of 2, fetal motion still compromises image quality. Therefore strategies are needed to further reduce time spent _acquiring_ the images (readout period).

Purpose: In this IRB approved study, we test the feasibility of a fetal imaging sequence consisting of a HASTE readout scheme preceded by two externally optimized skewed saturation pulses [1], which have been applied successfully as outer volume saturation pulses in the head at 7T. This method is termed ZOOmed Partially Parallel Acquisition (ZOOPPA) [2,3]. In ZOOPPA, the saturation pulse is optimized to provide a sharp, homogenous signal suppression in a desired area. In our case, the skewed pulse will suppress signal from the abdomen of a pregnant woman along the phase-encoding (PE) direction. This enables a _shorter readout train length_ by acquiring less k_y phase-encoding lines while maintaining the original resolution, and therefore making the images less susceptible to fetal motion.

Methods: Fetal acquisition was performed on 3T Skyra scanner (Siemens Healthcare, Erlangen, Germany) using a combined 18-channel body and 12-channel spine receive arrays. Two saturation pulses were prescribed perpendicular to the PE direction of a given slice prescription and positioned on either sides of the fetal head in order to suppress signal from the mother's abdomen. The sequence was designed to orient the saturation pulse perpendicular to the PE direction automatically and in real time as the user angulates the image orientation. To suppress unwanted signal, saturation pulses were played before the excitation pulse and were followed by crushers to spoil transverse magnetization within the saturated regions. It should be noted that both concurrently played pulses have a 30ms duration. Therefore, the transmitter voltage of the first saturation pulse was increased by 20% in order to account for T_1 recovery effects due to the length of the second saturation pulse. HASTE acquisition was acquired at matrix size of 256x256 over 30cm FoV with slice thickness of 3mm (overall voxel size of 1.2x1.2x3mm^3). Other imaging parameters include: echo spacing of 5.62ms, TE = 119ms, TR = 1.8s, partial Fourier of 5/8 and GRAPPA acceleration factor of R = 2. The SAR monitoring was always operated under normal mode to insure fetal safety.

Fig 1: Schematic of the sequence's timing diagram

Results: Fig 1 shows a simple schematic of the sequence's timing diagram. Fig 2 shows a representative slice of fetal brain diagnosed with Chairi II malformation from two HASTE acquisitions with identical imaging parameters, one of which applies the skewed saturation pulses (right) and the other does not (left). This figure shows the feasibility of the ZOOPPA HASTE acquisition in suppressing the abdomen tissue surrounding the fetal head. While the majority of the desired signal is suppressed, there is still some residual left. Note that the fetus has moved slightly between the acquisitions.

Discussion: The reduction of the HASTE readout length via ZOOPPA is achieved by increasing Δk_y in PE direction, which increases the effective in-plane acceleration factor. With saturation that contains some residual signal, as seen in our initial attempts (Fig 2), we can perform GRAPPA reconstruction at the full FoV and increase the effective in-plane acceleration to 4, resulting in 31% reduction in readout time compared to the original acquisition (R = 2, full FoV). In such case, the ZOOPPA technique acts to reduce residual aliasing that is typically associated with high in-plane accelerations since less signal from the

Figure 2 _Right:_ original HASTE acquisition; _Left:_ The identical HASTE acquisition (same imaging parameters) using two saturation pulses prescribed anterior and posterior to the fetal brain and also perpendicular to the PE direction. Both images are window-scaled equally. While a lot is suppressed, there is still some residual signal in the intended saturation regions;

saturated region is present to alias into the region of interest. As we improve saturation efficiency to achieve more ideal saturation, GRAPPA reconstruction can be performed at the current in-plane acceleration factor (R = 2) but with reduced FoV resulting in 37% reduction in readout time. _With such reductions in readout times the images will be less susceptible to fetal motion_. In the future, to achieve improved performance of the skewed pulses we will estimate transmit field (B_1^+) maps in the volume of interest in order to assure that the skewed saturation pulses operate at the appropriate transmit voltages. Also, doing fetal imaging with parallel transmit system can further help the performance of spatial saturation pulses in terms of achieving shorter pulse durations or playing the two saturation pulses in parallel on different transmit coil channels.

Conclusion: We have shown preliminary results demonstrating the feasibility and potential for reducing the _readout_ length of the HASTE acquisition for 3T fetal imaging while keeping the original voxel sizes, by applying outer volume skewed saturation pulses oriented perpendicular to the PE direction. Further optimization of the application of spatial saturation pulses in the pregnant abdomen is yet to be done. We believe that these methods are promising way to reduce the HASTE _readout_ length and thus will make the HASTE acquisitions less susceptible to fetal motion in the future.

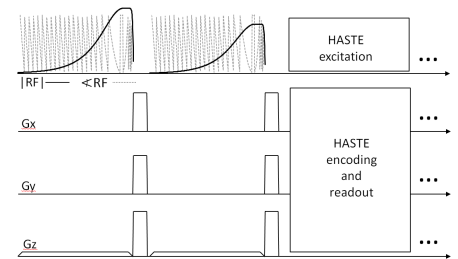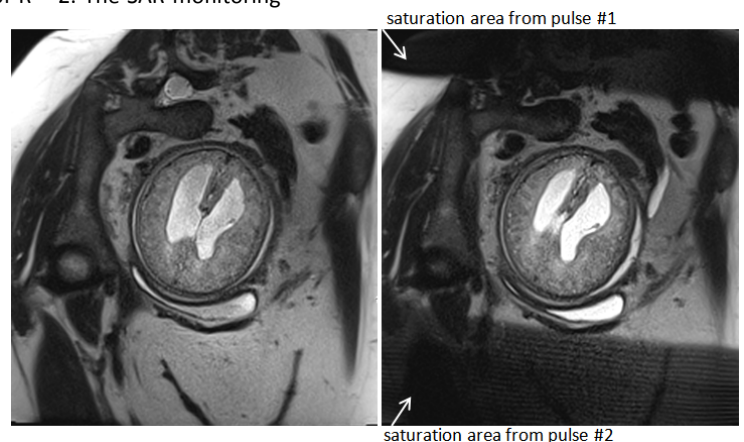**References:** [1] Pfeuffer J. NeuroImage 2002, 17:p272-286; [2] Heidemann R. MRM 2012; 68: p.25-33; [3] Heidenmann R. NeuroImage 2012 60:p967-978;