Non-contrast Magnetic Resonance Angiography of the fetal head and neck vessels

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Introduction: The fetal cardiovascular system is among the first systems to develop during embryonic life. Early in-utero detection of anomalies in the fetal vessels is important for planning clinical management. Doppler Ultrasound (US) and/or US based fetal echocardiography are the standard clinical tools used today for evaluating fetal vessels. However, the efficacy of these techniques is operator dependent and may be difficult to perform in cases like anhydromnios or abnormal fetal position. On the other hand, MRI is ideally suited for vascular imaging since they can have (a) large FOV (get the relation to other structures) (b) higher resolution (c) Not influenced by bony tissue or other conditions. Contrast enhanced magnetic resonance angiography (MRA) provides excellent visualization of the blood vessels. However, concerns over use of contrast agents in pregnancy preclude this technique from use human fetal imaging. Recent developments in high resolution non-contrast MRA provide a gateway for imaging fetal vasculature. Fetal vascular imaging is limited not only by the imaging resolution but also by motion artifacts. Among these, the most challenging aspect is fetal motion [1]. One way to avoid motion artifacts is to use compressed sensing (CS) techniques that exploits the sparse nature of MR angiograms and aids in the reduction of acquisition time. In this study we evaluated the feasibility of acquiring three dimensional non-contrast enhanced magnetic resonance angiographic (MRA) data in the human fetus and further, simulated a CS sampling scheme to evaluate the potential utility of CS reconstruction in fetal MR angiography.

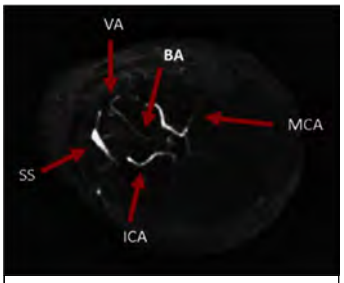

Fig 1. MIP of the cerebral vessels

$$x = \frac{\sqrt{\sum_{x,y}[\boldsymbol{I_0}(x,y) - \boldsymbol{I_{CS}}(x,y)]^2}}{\sum_{x,y}\boldsymbol{I_0}(x,y)}$$

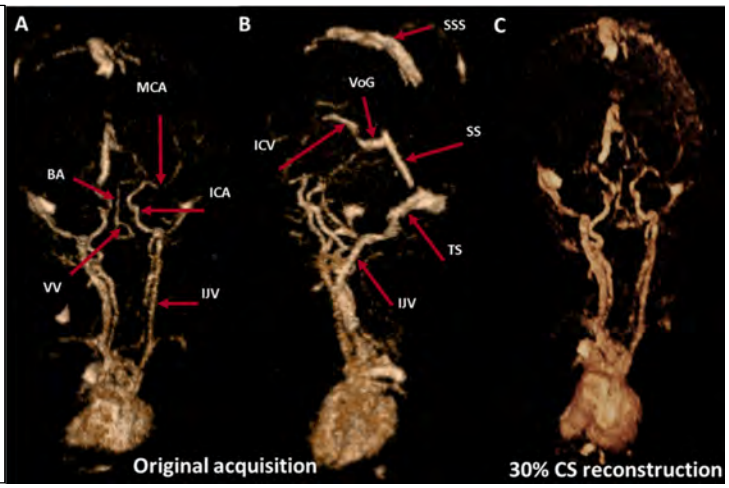

Fig 2. 3D rendering of the fetal vessels (A, B) TOF MRA shown in different views, (C) Simulated 30% CS reconstruction. MCA – middle cerebral artery; BA – basilar artery; ICA- internal carotid artery; VV – vertebral artery; IJV – internal jugular artery; SS – straight sinus; SSS – superior saggital sinus; TS – transverse sinus; VoG – vein of Galen; ICV – internal cerebral vein. (Gestational Age- 36 Weeks 4 days)

Methods: All MRI scans were performed on Siemens 3.0T Verio system. The standard 2D time of flight (TOF) MRA sequence used for imaging the adult vasculature was adapted to fetal imaging. The following aspects were considered while modifying the sequence: (a) specific absorption rate (SAR), (b) flow velocities in the vessels (c) vessel diameter and, (d) scan time. The resultant 2D sequence acquired a single slice of MRA data in approximately every 4 seconds with a reconstructed voxel size of 0.4-0.7 mm in-plane and 2 mm through plane with a TE- 4.92ms; TR – 22ms and FA - 50^0. The SAR of the implemented 2D MRA sequence was < 0.6 Watt/Kg. The quality of the MRA was reviewed by an experienced pediatric radiologist (SM) and the visualized vessels were noted. 3D rendering and maximum intensity projections (MIP) of the fetal vessels were created for visualization and for anatomical landmarking. For simulating a 2D CS sampling scheme, a mask with only 30% of total number of phase encoding lines (128), with variable density distribution, heavily densed at the center of k-space was created. This approach provided a gain of a factor of 3.3 in acquisition time. The mask was then applied on individual 2D k-space of every slice. The under-sampled k-space was then input into a CS reconstruction algorithm developed in MATLAB [1, 2]. Visual inspection and total relative error (TRE) (eq. 1) were used to evaluate performance of the CS reconstruction.

Results: The MRA data was acquired from 8 fetus (third trimester) with uncomplicated singleton pregnancies. The superior sagittal sinus, the transverse sinus, the basilar artery, the carotid arteries, the anterior cerebral artery, the middle cerebral artery, the posterior cerebral artery, the jugular veins and the vertebral veins were visualized. The 3D volume rendering and MIPs were also generated for visualization. The overall performance of CS is visually satisfying considering a factor of 3.3 gain in time and no visible under sampling artifacts (eg: aliasing or Gibbs Ringing). The TRE for the whole volume was 8.26×10^{-5} %. There is slight blurring across the CS reconstructed image which is an intrinsic CS artifact.

Discussion and Conclusion: To the best of our knowledge, this is the first report on the feasibility of consistently performing fetal MRA *in-vivo* on the third trimester fetus. Our results indicate that it is possible to perform fetal angiography while maintaining low SAR at 3.0T. This approach could further be extended to cover other fetal and potentially placental vessels as well. It may also be utilized as a good localizer for performing more quantitative imaging (phase contrast; SWI..etc). Data from third trimester fetuses is presented here. In principle, it is possible to obtain similar data in younger fetuses as well; although higher resolutions and longer TRs (due to slower blood flow rates) may be required which adversely affect the imaging time and increase the probability of fetal motion affecting the data. Thus methods for faster data acquisition like, faster k-space traversal approaches combined with CS and parallel imaging have an important role to play in fetal MR angiography. Simulation results in this study indicate that CS reconstruction can help in reducing the scan time without much loss in image quality for fetal MRA application.

References: [1] Prayer et.al., Fetal MRI, in Medical rad. Diag. 2011 [2] Lustig et.al., MRM, 2007. 58: p. 1182–1195. [3] Hamtaei et.al., *CS and joint imaging in MRI*. MS thesis 2013, dept. of BME, Wayne State University.