

## Magnetic resonance venography of the fetal brain using susceptibility weighted imaging (SWI)

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**Introduction:** Utilization of blood oxygen supply for metabolism is an integral part of human fetal growth process in-utero, specifically from the second trimester onwards. Injury to the developing fetal brain due to hypoxia-ischemia is a serious condition leading to considerable post-natal neurologic morbidity [1,2]. Ischemic perinatal stroke, is estimated to have an incidence of 1 in 1600 to 5000 births. Susceptibility weighted imaging (SWI) is as a venographic MR imaging technique which has been used successfully in evaluating stroke in the pediatric and neonatal populations [3,4] and more recently, even for quantitative evaluation of blood oxygenation [5]. SWI is a high resolution magnetic resonance (MR) imaging technique, which is much more sensitive than the typical T2\* based blood oxygen level dependent (BOLD) acquisition because of its unique combination of the T2\* weighted magnitude data with the phase data. Given the sensitivity of SWI to microhemorrhages, and deoxyhemoglobin, we anticipate that it may be useful in evaluating fetal hypoxia conditions. In this work present our initial experience with susceptibility weighted imaging in the fetus and evaluate its utility as a venographic imaging in the human fetus.

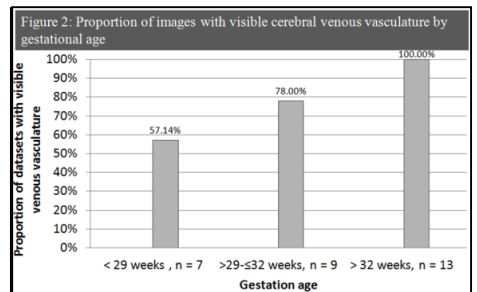
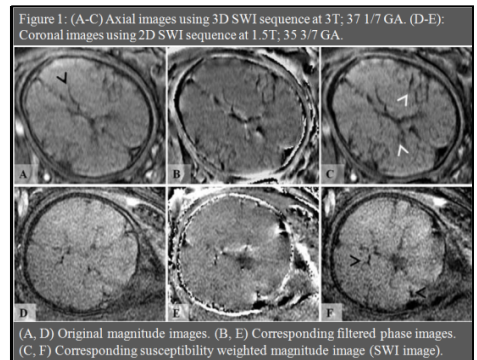
**Materials and Methods:** 29 pregnant women (gestation age (GA) interquartile range: 29.35-34.46 weeks) who were receiving care at Hutzel Women's Hospital in Detroit, MI, USA, were non-consecutively recruited. All subjects imaged in this study were recruited in accordance with local IRB guidelines and written informed consent was obtained from them prior to the MRI scan. Fetal MRI was performed at 1.5T using a GE system and/or at 3T Siemens system. The sequence

| Field Strength | Sequence Mode | TR (ms)    | TE(ms)       | In plane reconstructed voxel size (mm) | Slice Thickness (mm) | BW (Hz/pixel) | # of Slices |
|----------------|---------------|------------|--------------|--|----------------------|---------------|-------------|
| 1.5T           | 2D            | 100 or 105 | 33.7         | 0.7 x 0.7                              | 5 to 6               | 122           | 12          |
|                | 3D            | 250 to 280 | 17 to 19     | 0.78 x 0.78                            | 3 to 3.5             | 199           | 11          |
| 3T             | 2D            | 20 to 23   | 13.5 to 17.3 | 0.78 x 0.78                            | 3 to 3.5             | 219           | 16          |

parameters for both the 2D and 3D SWI datasets are shown in Table 1. **Post-processing:** SWI phase images were first filtered using a mild homodyne [6] high pass filter (HPF) of size 32 x 32. After filtering, HPF phase information was used to enhance the contrast of the corresponding SWI magnitude images. **Analysis:** SWI data from all the subject scans were evaluated by a pediatric neuroradiologist for overall image quality using an ordinal quality scoring scheme. The ordinal quality scoring criteria is given in Table 2. Images of diagnostic quality with good magnitude definition and no artifacts were given the score of 1. Image volumes with minor artifacts but still of diagnostic quality were scored 2. Images of non-diagnostic quality with poor magnitude definition and major artifacts were scored 3. Among the one or more SWI datasets scored from a given fetal scan, maximum of the scores is taken as the final score for that scan. Both 2D and 3D SWI data were scored individually for image quality. Furthermore, in each fetus's scan, irrespective of whether it was 2D or 3D SWI, processed SWI images were evaluated for visibility of cerebral venous vasculature using a dichotomous, Yes/No classification.

| Score | Interpretation  | # of data sets receiving the score |
|-------|---|------------------------------------|
| 1     | Diagnostic quality images with good magnitude definition and no artifacts             | 19                                 |
| 2     | Minor artifacts being present but overall image volume is still of diagnostic quality | 8                                  |
| 3     | Non-diagnostic images, very poor magnitude definition containing major artifacts      | 5                                  |

**Results:** Of the 29 fetuses, 3 fetuses exhibiting abnormalities underwent MR imaging twice bringing the total number of SWI data evaluated in this study to 32. 2D SWI data were collected in all subjects except one (n=31), whereas 3D-SWI data were collected when total scan time restrictions permitted (n=19). The phase signature of the veins due to their paramagnetic nature is clearly visible in the images [Figs. 1(B), 1(E)] and clearly helps in enhancing magnitude contrast after SWI processing [Figs. 1(C) and 1(F)]. Of 32 fetal SWI scan datasets scored, 59% (n=19) were found to be of diagnostic quality with no artifacts and received the optimal score of 1. Minor artifacts were seen in 25% (n=8) of the datasets which were still of diagnostic quality and received a score of 2. In 16% (n=5) of the datasets, images were of non-diagnostic quality and received a score of 3 (see Table 2). Cerebral venous vasculature was visible in 81.25% (n=26) of the SWI datasets. Veins were visible in 57.1% (4/7) of those observations obtained prior to 29 weeks of gestation and in 78% (7/9) of those obtained between 29 and 32 weeks. After 32 weeks of gestation, cerebral venous vasculature was visible in all observations (13/13). Excluding repeated measurements from a fetus, the likelihood of viewing cerebral venous vasculature increased significantly as a function of gestational age (OR 1.6; 95% CI 1.2-2.5; p=0.02). Figure 2 illustrates this association by showing the proportions of images in which venous vasculature were viewable by categorical gestational age. Figure 3 shows cerebral SWI venograms from fetuses at different gestational ages. Major deep gray matter veins like thalamostriate veins, internal cerebral veins and basal vein of Rosenthal are clearly visualized at later gestational ages.



**Discussion:** SWI data which received a score greater than or equal to 2, typically had coil drop-off (i.e., varying signal to noise ratio (SNR), from high to low across the image) or susceptibility related artifacts which slightly affected the image quality. Despite the short scan time of 20 to 25 seconds, similar to other imaging sequences currently used in fetal MRI, SWI also had to be repeated multiple times when motion had degraded the image quality severely. We see a progressively increased visibility of venous vasculature with increasing GA. Visibility of veins in SWI is a function of the deoxyhemoglobin content of venous blood. Hence this increase in venous vessel visibility could imply either (a) a developing fetal venous vasculature, or (b) a progressively increasing deoxyhemoglobin content within them with increasing GA or (c) both. An imaging method independent of the deoxyhemoglobin content of blood, like for example non-contrast Magnetic Resonance Angiography (MRA) would be required to tease out which of these factors is the primary reason for this variation in venous visibility. A key point in this study is that the existing conventional SWI sequence was modified by changing the typical user defined sequence parameters. This shows that performing fetal SWI in the clinical setting is readily possible without additional sequence programming. However, further efforts are necessary to improve the quality of data acquisition to increase the visibility of the smaller vessels. Moreover, fetal motion continues to be a problem despite short scan times. Faster scan times with higher resolution acquisition may be possible by employing segmented data acquisition techniques in combination with parallel imaging and novel reconstruction schemes.

**Conclusion:** To summarize, we have demonstrated the feasibility of performing fetal cerebral venography using SWI. To the best of our knowledge this is the first application of SWI in the fetus and based on SWI's current role in neonatal and pediatric stroke we anticipate that, it may have an important role in imaging fetal stroke.

**References:** [1] Wu YW, et al., Pediatrics 2004;114:612-9. [2] Lynch JK. Semin Fetal Neonatal Med. 2009;14(5):245-9. [3] Ashwal S et al., Arch Phys Med Rehabil. 2006;87(12 Suppl 2):S50-58. [4] Lequin et al., Semin Fetal Neonatal Med. 2009;14(5):299-310. [5] Haacke EM, et al., JMIR 2010;32(3):663-676. [6] Haacke EM, et al., MRM, 2004;52(3):612-618.

