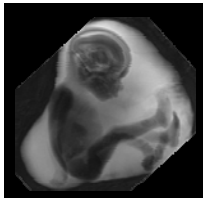
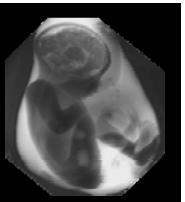




IN VIVO MAGNETIC RESONANCE ANGIOGRAPHY OF FETAL VASCULATURE

Jaladhar Neelavalli[1,2*], Swati Mody[1], Uday Krishnamurthy[1,2], Pavan K. Jella[1], Brijesh K. Yadav[1,2], Edgar Hernandez-Andrade[3,4], Lami Yeo[3,4], Maria D. Cabrera[1], Ewart M. Haacke[1,2], Sonia S. Hassan[3,4], Roberto Romero[4]

[1]Department of Radiology, [2]Department of Biomedical Engineering, [3]Department of Obstetrics and Gynecology Wayne State University [3]Perinatology Research Branch, NICHD/NIH/DHHS, Bethesda, Maryland, and Detroit, Michigan, USA

Jaladhar Nelavalli: jneelava@med.wayne.edu

DMC Children's Hospital of Michigan

WAYNE STATE

Eunice Kennedy Shriver NICHD National Institute of Child Health & Human Development

Background

- Ultrasound (US) is the primary modality for fetal imaging
- Doppler imaging is the mainstay for evaluating fetal vasculature
    - 3D/4D ultrasound and Spatiotemporal Image Correlation (STIC)

Background

- **Fetal MRI is valuable as an adjunct to US for fetal assessment**
- **Recently, non-contrast MR angiography has been performed in fetal sheep[1]**
- **Explore the possibility of performing MR Angiography in human fetus without IV contrast**

(1)Yamamura, Jin, et al. "Magnetic resonance angiography of fetal vessels: feasibility study in the sheep fetus." *Japanese journal of radiology* 28.10 (2010): 720-726.

Motivation: MR Angiography (MRA)

JOURNAL OF MAGNETIC RESONANCE IMAGING 40:949–957 (2014)

Original Research

MR Venography of the Fetal Brain Using Susceptibility Weighted Imaging

Jaladhar Neelavalli, PhD,[1*] Swati Mody, MD,[2] Lami Yeo, MD,[3,4] Pavan Kumar Jella, MS,[1] Steven J. Korzeniewski, PhD,[3,4] Sheena Saleem, DNB, MBBS,[2] Yashwanth Katkuri, MS,[1] Ray O. Bahado-Singh, MD,[3] Sonia S. Hassan, MD,[3,4] E. Mark Haacke, PhD,[1] Roberto Romero, MD, DMed Sci,[4,5,6†] and Moriah E. Thomason, PhD[4,7]

JOURNAL OF MAGNETIC RESONANCE IMAGING 39:998–1006 (2014)

Technical Note

Measuring Venous Blood Oxygenation in Fetal Brain Using Susceptibility-Weighted Imaging

Jaladhar Neelavalli, PhD,[1*] Pavan Kumar Jella, MS,[1] Uday Krishnamurthy, MS,[1] Sagar Buch, MS,[2] E. Mark Haacke, PhD,[1] Lami Yeo, MD,[3,4] Swati Mody, MD,[5] Yashwanth Katkuri, MS,[1] Ray Bahado-Singh, MD,[3] Sonia S. Hassan, MD,[3,4] Roberto Romero, MD, D Med Sci,[4†] and Moriah E. Thomason, PhD[4,6]

Krishnamurthy, Uday, et al. Quantitative flow imaging in the human umbilical vessels in-utero using non-triggered phase contrast MR" ISMRM (2014)

Motivation: MR Angiography (MRA)

- To map fetal vasculature for quantitative MRI
- Perform fetal MRA in patients where Doppler imaging is suboptimal
  - Maternal obesity
  - Fetal position

Study Objective

- To assess the feasibility of performing non-contrast MR Angiography in the human fetus using the Time of Flight (TOF) technique

Fetal MRA: Study Population

- Third trimester fetuses (n=6; 26-37 weeks)
- Receiving prenatal care at Hutzel Women's Hospital
- Study was conducted in accordance with local IRB guidelines
- MRA was performed as subset of a larger fetal imaging study

Fetal MRA: Technique

- 3.0T Siemens Verio system (Erlangen, Germany)
  - 6 channel body flex array + 4 channel spine receive coils
  - 2 channel extremity flex coil (if necessary)
- Scanning was performed without maternal breath holds
- No maternal sedation

Fetal MRA: Technique

Considerations for sequence modification

1. Fetal motion
   - 2D instead of 3D imaging
2. Increased Velocity within fetal vessels
   - Increase T1 / inflow weighting
3. Smaller dimensions of the fetal vessel lumen
   - Use high imaging resolution
4. Specific Absorption Rate (SAR)
   - Reduce by increasing TR[1]

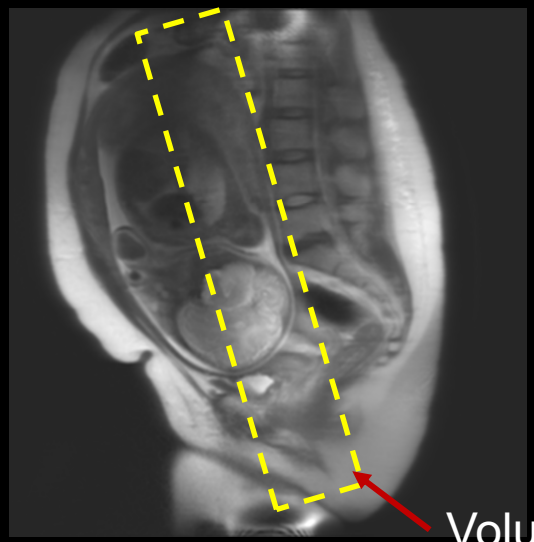
(1) Krishnamurthy, Uday, et al. "MR imaging of the fetal brain at 1.5 T and 3.0 T field strengths: comparing specific absorption rate (SAR) and image quality."*Journal of perinatal medicine* (2014).

Fetal MRA: Technique

	Mode	TE (ms)	TR (ms)	Reconstructed Resolution (mm^3)	Flip Angle (degrees)	Band width (Hz/pixel)	# of Slices	Tot. Acq. Time (min)
Conventional	3D	3.4-11.3	25	(0.75 - 1)x (0.75-1)x(1.2-2)	20	42	50-70	5-7
Fetal	2D	4.92	22	(0.4-0.7) x (0.4-0.7)x(1.5-2)	50	241	26-64	2-5

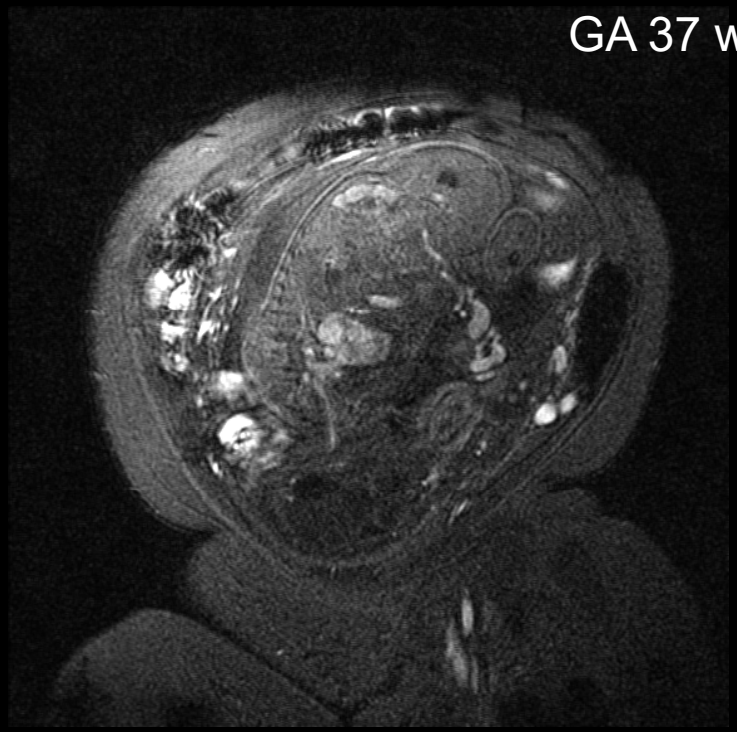
- For faster imaging to mitigate fetal motion artifacts
- For greater T1 weighting and for reducing the SAR
- For increased T1 weighting

Fetal MRA: Technique



Localizer image

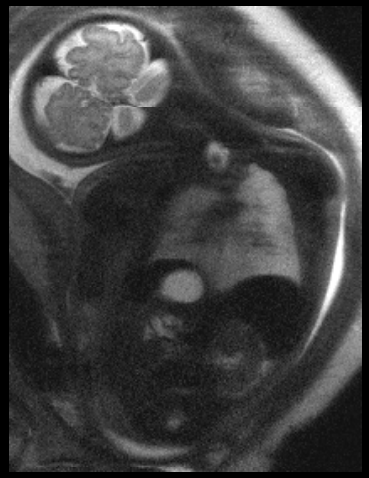
GA 37 weeks

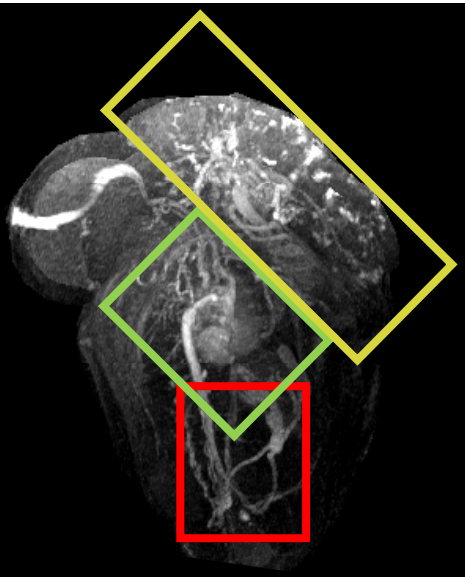


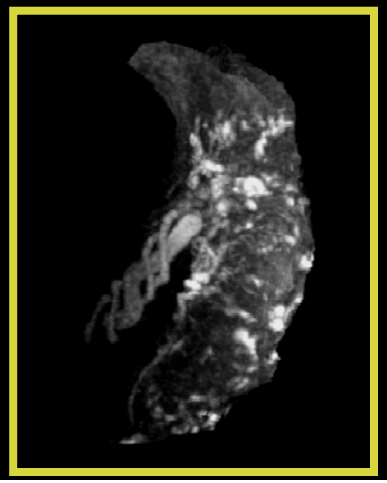
2D raw data images

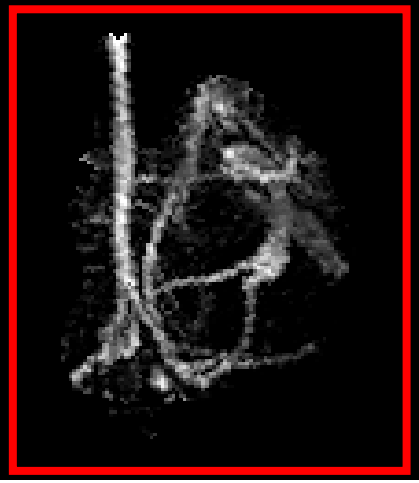
Fetal MRA: Technique

ROI for relevant vasculature was manually cropped to generate volumes for 3D visualization

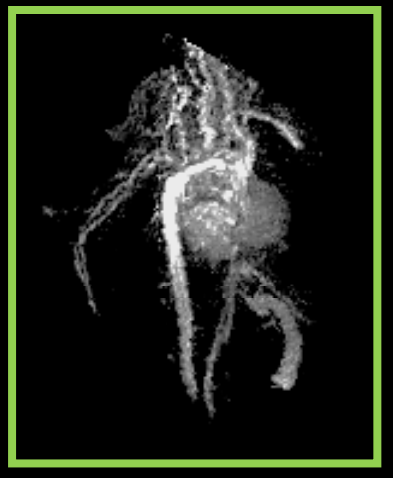






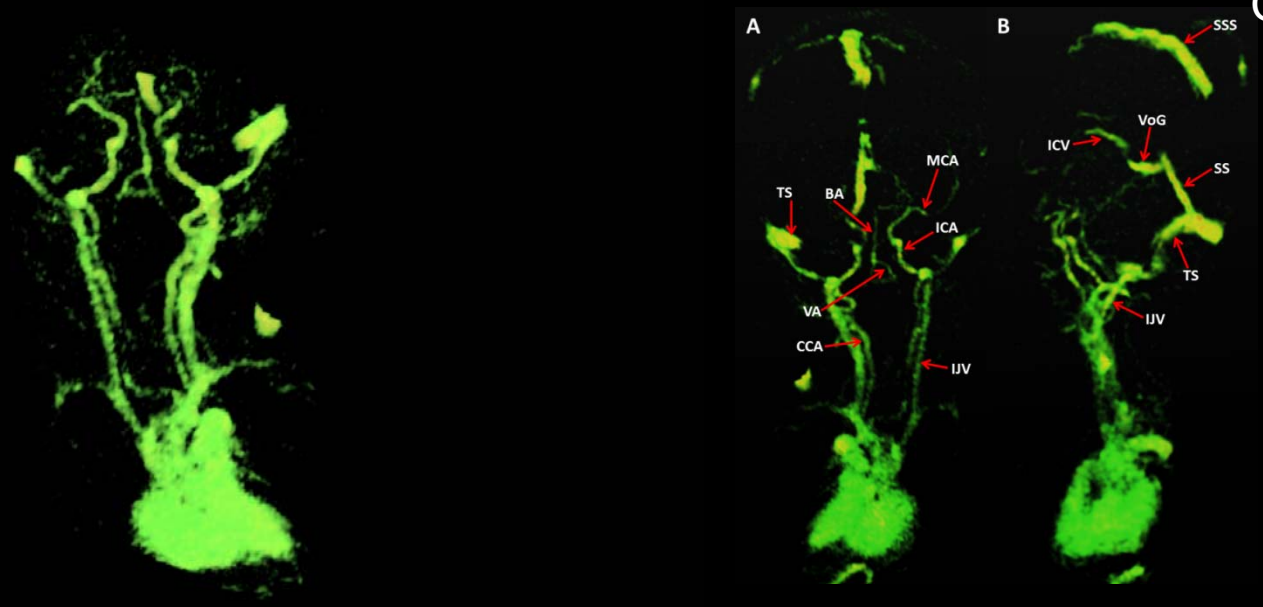


GA: 36 3/7 weeks



MRA of Fetal Head and Neck

GA: 36 4/7

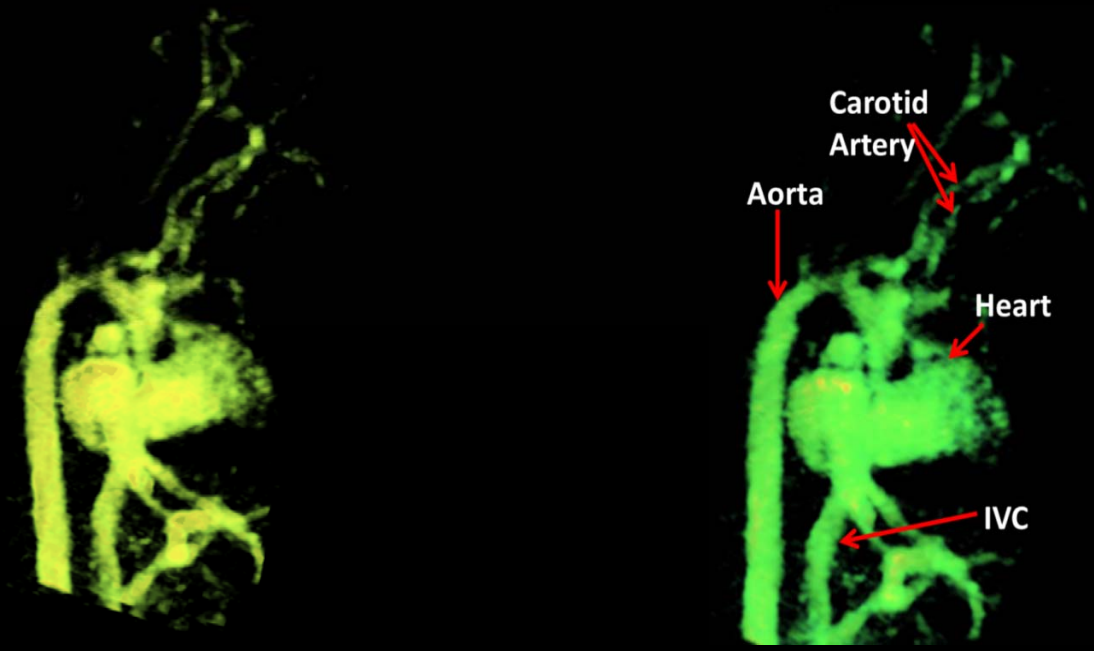


3D MRA of fetal head and neck vessels:

MCA: middle cerebral artery; BA: basilar artery; ICA: internal carotid artery; VA: vertebral artery; IJV: internal jugular artery; SS: straight sinus; SSS: superior sagittal sinus; TS: transverse sinus; VoG: vein of Galen; ICV: internal cerebral vein.

MRA of Fetal Chest and Upper Abdomen

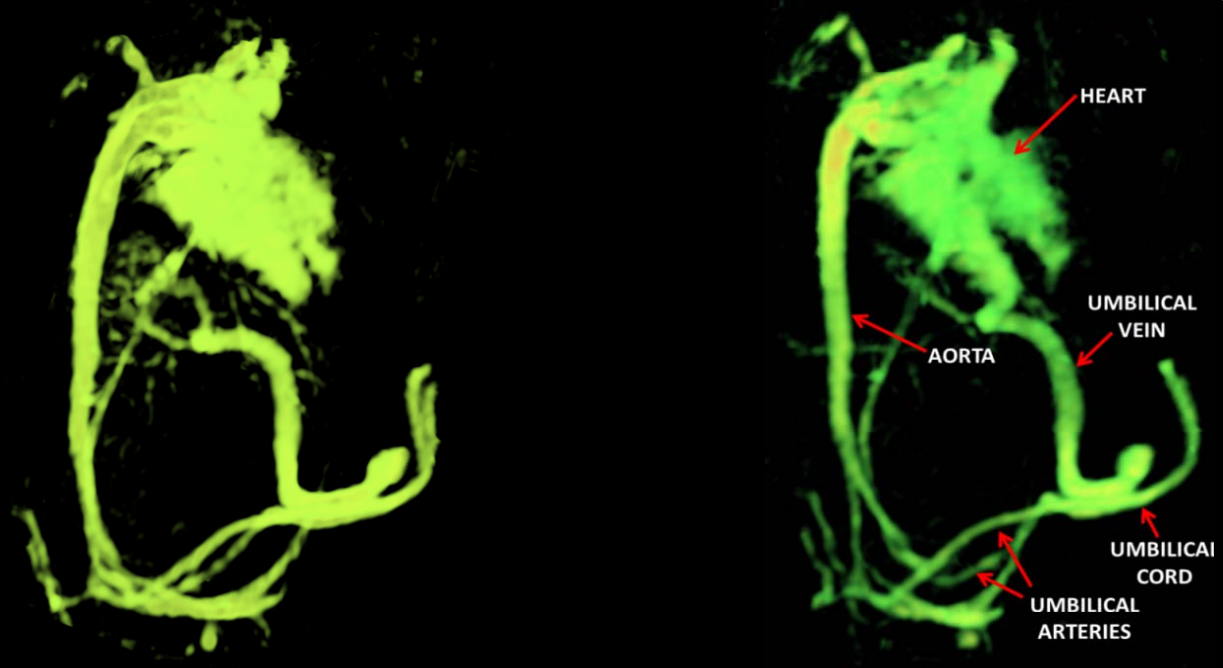
GA: 37 1/7



3D MRA of the fetal fetal chest and upper abdomen showing the major arterial (Aorta, carotid arteries) and the venous (inferior venacava) structures.

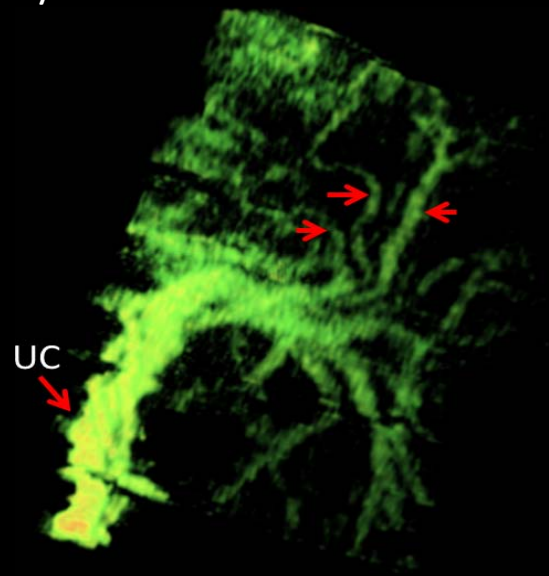
MRA of Fetal Circulation

GA: 36 4/7



MRA of the Placenta

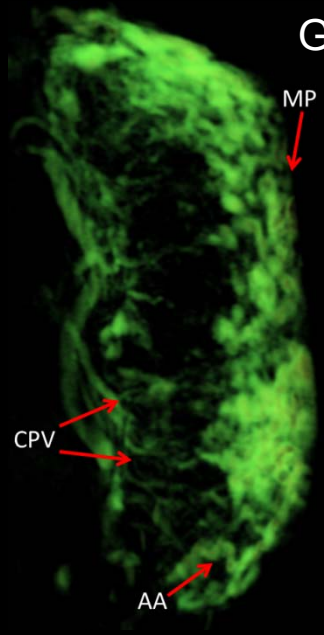
GA : 36 4/7 weeks



MRA at the origin of umbilical cord

Vessels on the chorionic plate (red arrows)
umbilical cord (UC)

GA 29 weeks



MRA of placental vasculature

Vessels on the maternal side (MP)
Chorionic plate of the placenta (CPV)

Clinical Utility of Fetal MRA

- Exploring clinical utility
- Suboptimal Doppler imaging – Maternal obesity, fetal position
- High resolution - improved visualization of fetal vasculature
  - Small vessels head and neck region
  - Placenta
- Large Field of view
  - Placenta
  - Global perspective of fetal vasculature
    - May be helpful for large vascular malformations or syndromic vascular malformations such as Klippel-Trenaunay-Weber, Osler-Weber-Rendu

Quantitative Imaging: Fetal MRA

- **Localize blood vessels for quantitative imaging**
  - **Perfusion (ASL)**
  - **Blood oximetry[1]**
  - **Phase-contrast based flow imaging[2]**

(1) Neelavalli, Jaladhar, et al. "Measuring venous blood oxygenation in fetal brain using susceptibility-weighted imaging." *Journal of Magnetic Resonance Imaging*39.4 (2014): 998-1006.
(2) Krishnamurthy, Uday, et al. “Quantitative flow imaging in the human umbilical vessels in-utero using non-triggered phase contrast MR” ISMRM (2014)

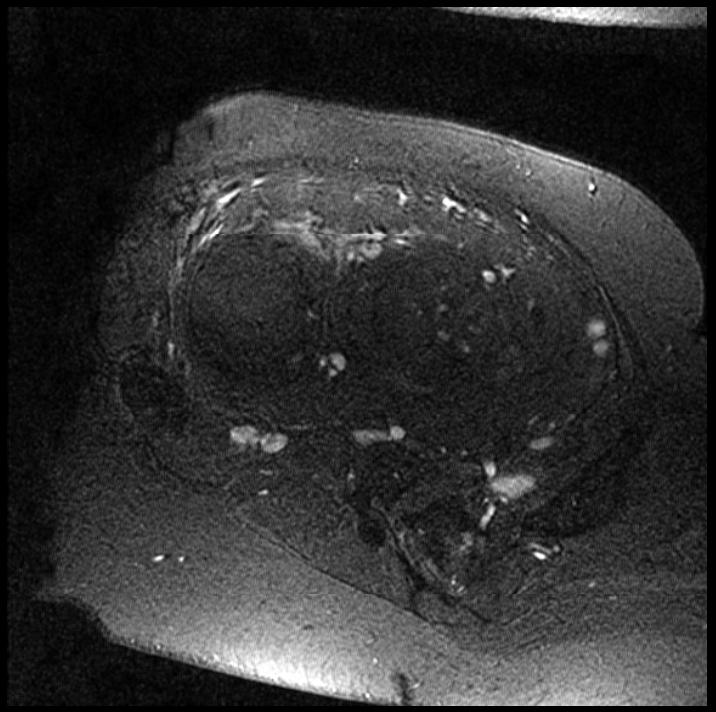
Fetal MRA at 3.0 Tesla

- Advantages of 3.0T MRA
  - Increased T1 weighting
  - Higher SNR
    - Ability to image at higher resolution
    - Shorter scan time

Fetal MRA: Challenges

- **Orientation**
  - **Relative to the slice (improved if the slice is perpendicular to the vessel)**
- **Artifacts**
  - **RF Inhomogeneity (excitation and phased array coil reception)**
  - **Banding (Susceptibility)**
- **Fetal Motion**

GA 26 weeks



Fetal MRA: Future Directions

- **Need to optimize technique for diagnostic application**
  - **Higher resolution Imaging**
  - **Faster scan time**
    - **Use radial/spiral reduced data reconstruction**
    - **Use compressed sensing [1]**
  - **Coils with higher number of phased array elements (parallel imaging acceleration factor)**

(1) Hamtaei, Ehsan et al. “Compressed Sensing MRA in the Human Fetus” 36th Annual International Conference of the IEEE EMBC (2014)

Conclusion

- Human fetal MR Angiography is feasible with modification of conventional TOF technique
- Critical first step for future quantitative MR vascular imaging in the human fetus and placenta

References

[1] Brown, R. W., Cheng, Y. C. N., Haacke, E. M., Thompson, M. R., & Venkatesan, R. (2014). *Magnetic resonance imaging: physical principles and sequence design*. John Wiley & Sons.

[2] Yamamura, Jin, et al. "Magnetic resonance angiography of fetal vessels: feasibility study in the sheep fetus." *Japanese journal of radiology* 28.10 (2010): 720-726.

[3] Neelavalli, Jaladhar, et al. "Measuring venous blood oxygenation in fetal brain using susceptibility-weighted imaging." *Journal of Magnetic Resonance Imaging*39.4 (2014): 998-1006.

[4] Krishnamurthy, Uday, et al. “Quantitative flow imaging in the human umbilical vessels in-utero using non-triggered phase contrast MR” ISMRM (2014)

[5] Krishnamurthy, Uday, et al. "MR imaging of the fetal brain at 1.5 T and 3.0 T field strengths: comparing specific absorption rate (SAR) and image quality."*Journal of perinatal medicine* (2014).

[6] Hamtaei, Ehsan et al. “Compressed Sensing MRA in the Human Fetus” 36th Annual International Conference of the IEEE EMBC (2014)

Thank You