Fetal Cardiovascular Magnetic Resonance

Over recent years a number of groups have been investigating the utility of MRI for fetal cardiovascular imaging. Initial reports focused on the application of steady state fast precession (SSFP) for identifying cardiac anatomy, showing that it was possible to identify cardiac structures and diagnose cardiac malformations in fetal subjects using this approach (1) (2) (3) (4). Other groups have investigated the potential of MRI to provide some form of functional information about the fetal cardiovascular system. These include an early description of "real-time" cine SSFP to measure ventricular sizes and ejection fractions (5). Other groups have sought to achieve higher resolution cine imaging by introducing triggered cardiac imaging. As the fetal ECG signal is not readily available in the MRI environment, alternative methods for gating have been tried. These include ultrasound based technology which has been modified for use in the MRI and a "self-gated" approach, both of which have been shown to be effective ways to achieve high resolution fetal cardiac imaging in animal models (6) (7) (8). Another approach known as metric optimized gating (MOG) takes temporally oversampled data and retrospectively re-orders it through a range of candidate heart rates (9) (10). The most appropriate reconstruction is identified using an image metric as the arrangement resulting in the least artifact. MOG can be used for reconstructing anatomical cine SSFP and cine phase contrast velocity mapping and the code for MOG has been published as a free internet download and can be operated in MATLAB (11).

Additional technical challenges to fetal CMR include the small size of the vessels and fetal motion. However, the body movements of late gestation fetuses are relatively restricted and the vessel sizes approach those of neonates, allowing for established criteria for spatial and temporal resolution to be achieved with realistic scan times (12). Accelerated sequences and motion correction algorithms are resulting in significant improvements in image quality (13) (14). However, as yet, no established indications for fetal CMR have emerged. This is partly because of the superlative image quality of fetal echocardiography, and the wealth of hemodynamic information that is available from Doppler. However, direct information about fetal oxygenation can be obtained by exploiting the different magnetic properties of oxygenated and deoxygenated blood, and this may represent an advantage of fetal CMR over traditional Doppler parameters, which identify fetal distress through the demonstration of indirect fetal circulatory adaptations to hypoxia. Techniques for investigating fetal oxygenation with MRI include Blood Oxygen Level Dependent (BOLD) MRI and MR oximetry, which can be achieved with T2 mapping (15) (16) (17). There remains much to be done in terms of calibrating these measurements for fetal hemoglobin and accounting for variation in hematocrit (18). However, the combination of flow quantification with PC MRI and measurement of the oxygen content of blood has provided a new technique for assessing placental function, fetal oxygen transport and metabolism, and is already providing new insights into the relationship between fetal cardiovascular physiology and fetal development in conditions like congenital heart disease and intrauterine growth restriction (19) (20).

Bibliography

1. *Feasibility of fetal cardiac magnetic resonance imaging: preliminary experience.* **Gorincour, G, et al.** 2007, Ultrasound in Obstetrics and Gynecology, Vol. 29, pp. 105-108.
2. *Feasibility of MRI of the Fetal Heart with Balanced Steady-State Free Precession Sequence Along Fetal Body and Cardiac Planes.* **Saleem, SN.** 2008, Am J Roentgenol, Vol. 191, pp. 1208-1215.
3. *Potential role of fetal cardiac evaluation with magnetic resonance imaging: preliminary experience.* **Manganaro, L, et al.** 2008, Prenatal Diagnosis, Vol. 28, pp. 148-156.
4. *Preliminary experience with cardiovascular magnetic resonance in evaluation of fetal cardiovascular anomalies.* **Dong, SZ, Zhu, M and Li, Fen.** 2013, J Cardiovasc Magn Reson, Vol. 15, p. 40.
5. *Preliminary investigations into a new method of functional assessment of the fetal heart using a novel application of "real-time" cardiac magnetic resonance imaging.* **Fogel, MA, et al.** 2005, Fetal Diagn Ther, Vol. 20, pp. 475-80.
6. *Noninvasive self-gated magnetic resonance cardiac imaging of developing chick embryos in ovo.* **Holmes, WM, et al.** 2008, Circulation, Vol. 117, pp. e346-e347.
7. *Cardiac MRI of the fetal heart using a novel triggering method: initial results in an animal model.* **Yamamura, J, et al.** s.l. : J Magn Reson Imaging, 2012, Vol. 35, pp. 1071-6.
8. *Self-gating MR imaging of the fetal heart: comparison with real cardiac triggering.* **Yamamura, J, et al.** 2011, Eur Radiol, Vol. 21, pp. 142-9.
9. *Metric optimized gating for fetal cardiac MRI.* **Jansz, MS, et al.** 5, 2010, Magn Reson Med, Vol. 64, pp. 1304-14.
10. *Dynamic imaging of the fetal heart using metric optimized gating.* **Roy, CW, et al.** 6, 2013, Magn Reson Med, Vol. 70, pp. 1598-607.
11. **Macgowan, CK.** *Metric Optimized Gating.* s.l. : http://metricoptimizedgating.github.io/MOG-Public/ .
12. **Seed, M.** Fetal Cardiovascular MRI. [book auth.] B Kline-fath, R Bahado-Singh and DI Bulas. *Diagnostic Imaging of Fetal Anomalies: Ultrasound and MRI.* Philadelphia : Lippincott Williams and Wilkins, 2015, pp. 228-234.
13. *Time-Resolved Fetal Cardiac MRI Using Compressed Sensing and Metric Optimized Gating.* **Roy, CW, Seed, M and Macgowan, CK.** Toronto : International Society of Magnetic Resonance in Medicine, 2015.
14. *Myocardial T2 mapping with respiratory navigator and automatic nonrigid motion correction.* **Giri, S, et al.** 2012, Magn Reson Med, Vol. 68, pp. 1570-1578.
15. *Functional MR imaging: comparison of BOLD signal intensity changes in fetal organs with fetal and maternal oxyhemoglobin saturation during hypoxia in sheep.* **Wedergartner, U, et al.** 2006, Radiology, Vol. 238, pp. 872-80.
16. *Changes in human fetal oxygenation during maternal hyperoxia as estimated by BOLD MRI.* **Sorensen, A, et al.** 2013, Prenat Diagn, Vol. 33, pp. 141-5.
17. *In vivo MRI measurement of fetal blood oxygen saturation in cardiac ventricles of fetal sheep: a feasiblity study.* **Wedergartner, U, et al.** 2010, Magn Reson Med, Vol. 64, pp. 32-41.
18. *Combined T1 and T2 Measurement for Non-Invasive Evaluation of Blood Oxygen Saturation and Hematocrit.* **Portnoy, S, et al.** 2015. ISMRM.

19. *Reduced fetal cerebral oxygen consumption is associated with smaller brain size in fetuses with congenital heart disease.* **Sun, L, et al.** 2015, Circulation, Vol. 131, pp. 1313-1323.
20. *The hemodynamics of late-onset intrauterine growth restriction by MRI.* **Zhu, MY, et al.** 2015, American Journal of Obsetetrics and Gynecology, Vol. http://dx.doi.org/10.1016/j.ajog.2015.10.004, pp. 1-24.