

A Novel Technique for Cardiac MRI of the Fetal Heart: MR compatible Doppler Ultrasound (CTG) for CardiacTriggering

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Introduction

The importance of fetal magnetic resonance imaging (MRI) in prenatal diagnostic has significantly increased in recent years. Although the fetal MRI has already been applied to almost all fetal organs, the fetal heart has not been widely evaluated so far due to technical problems. Cardiac imaging usually requires electro-cardiogram (ECG) triggering during measurements. Since the fetal heart lies within the uterus, there is no possibility for a direct triggering of the fetal heart frequency. The visualization of anomalies both of the heart and the great vessels is of great importance for prenatal diagnostics; however it is not yet feasible.

One study modified a Doppler ultrasound monitor and used it for fetal monitoring during magnetic resonance imaging performed on a 0.5 T [1]. In a more recent study a CTG was modified and optimized to make it MRI compatible. Using this device the fetal heart rate could be monitored during the MR examination, although there were somewhat artifacts and the signal was not continuous [2]. This device was surely good enough to monitor the fetal heart rate and movement, but would not be suitable to use it as cardiac triggering. The challenge was to develop a CTG that is stable enough to provide Doppler signal throughout the whole MR examination without any artifact to use the signal as cardiac triggering in a more clinical setting, e.g. in a 1.5 T MR scanner.

In the here presented feasibility study, a newly developed MRI compatible cardiotocogram (CTG) stable enough during the whole scanning time was introduced for the first time. A commercially available CTG was modified, so that the heart beat could be recorded during the whole scanning time without any artifacts. The aim of this study was to perform fetal cardiac MR imaging with triggering of the fetal heart beat in utero with a novel MR compatible cardiotocogram (CTG) in a sheep model.

Material and Methods:

Triggering using CTG: The ultrasound transducer (HP 15245A) of a standard CTG (model HP 8040A, Hewlett Packard, Palo Alto, USA) was employed for cardiac MRI triggering instead of the routine 4-lead ECG. In a first step, all magnetically perturbing components of the CTG's ultrasound transducer were replaced by non-magnetic materials and components of low magnetic signature. In the second step, the CTG signal was protected against the electrical and magnetic fields' interference of the MRI. In the last step, an additional optical transmission and standardization of the heart signal was used to put the analogue signal back to the ECG-unit of the MRI.

MR imaging of the fetal heart: Images of the fetal sheep heart were performed on 5 pregnant ewes at a 1.5 T scanner (Siemens, Erlangen, Germany) with a 4 element phased array body coil. The ultrasound probe of the CTG was placed directly on the abdominal wall of the maternal sheep to record the cardiac frequency of the fetus as a Doppler sound. Thus cardiac triggered cine MRI sequences with steady-state free precession (SSFP) (TR 34.91 ms; TE 1.34 ms; FoV 400 ms; Flip-angle 55°; slice thickness 3 mm) of the fetal heart were achieved in short axis view, two, four and three chamber view. From the short-axis, the left ventricular volume and thus the function were measured.

Results:

The fetal heart frequencies were between 130 and 160 beats per minute. The novel MR compatible CTG allowed a stable signal during the whole MRI measurement. It was possible to perform the CTG triggered fetal cardiac MRI in all fetuses. In cine sequences the contraction was shown. The average blood volumes at end systole were 2.9 ml ($SD \pm 0.2$), at end diastole 4.6 ml (± 0.2); with ejection fractions between 38.4% and 40%, respectively. The mitral, the tricuspid, aortic and the pulmonary valves as well as the foramen ovale were clearly depicted (Figure 1-3).

Discussion and Conclusion:

The novel MR compatible CTG allowed an excellent trigger of the fetal heart rate. An evaluation of anatomical structures and functional information could be obtained from the cMRI. A CTG triggered fetal cardiac MRI might be of great impact in the evaluation of fetuses with complex congenital heart defects.

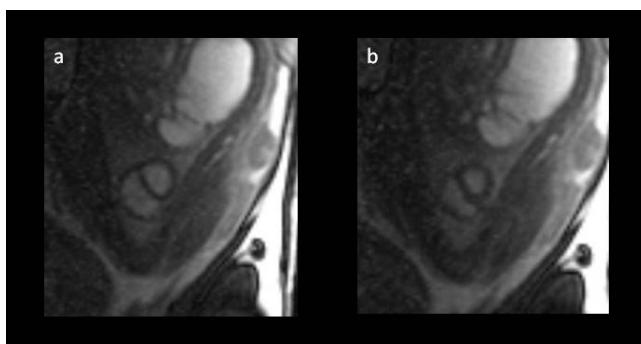


Figure 1: Short axis view of the fetal heart in diastole (a) and systole (b). The contraction of the fetal heart could be observed in real time cine sequences.

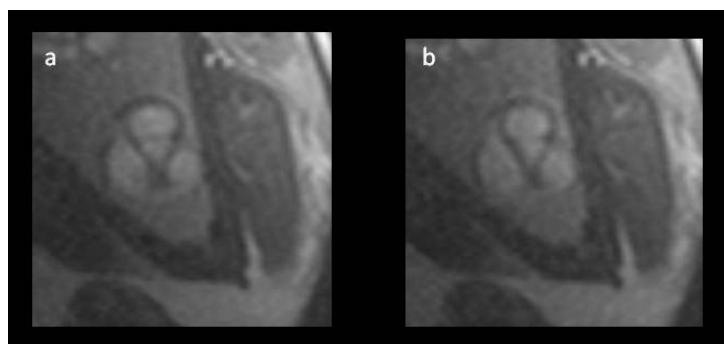


Figure 2: Axial view of the aortic valve. The aortic valve can be seen in both closed (a) and opened (b) condition.



Figure 3: Four chamber view of the fetal heart. The mitral and the tricuspid valves can be detected with the novel technique.

References:

1. Shakespeare, S.A., et al., A method for foetal heart rate monitoring during magnetic resonance imaging using Doppler ultrasound. *Physiol Meas*, 1999. 20: p. 363-368.
2. Michel, S.C., et al., Original report. Fetal cardiographic monitoring during 1.5-T MR imaging. *AJR Am J Roentgenol*, 2003. 180: p. 1159-1164.