MRI Triggering by a Doppler Ultrasound at 1.5 T for Future Fetal Cardiac Function Investigation

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Abstract

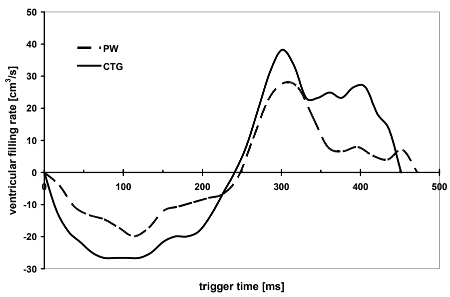
Introduction
One of the greatest challenges in the fetal MR imaging is the evaluation of the fetal heart. Usually the cardiac imagings in adults are ECG triggered and is made with breathhold of the patient. Since the fetal heart lies within the uterus, a direct triggering of the heart frequency of the fetus is not possible. Cardiac MRI triggering by Doppler ultrasound is suffering from magnetic artifacts by the transducer and the interference between the ultrasound and the MR signal. This feasibility study is based on performing cardiac MR imaging of the fetal heart in utero. The Doppler ultrasound probe of a standard cardiotocograph (CTG) was re-designed as a triggering device to be MRI compatible. The obtained images were compared with images from pulse-wave (PW) triggering of the fetal heart.

Material and Methods
The transducer was dismantled and all electronic parts were separately scanned on the water phantom. All of them generated magnetic artifacts except the piezoelectric crystals.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 a second step, the CTG signal was protected against the electro-magnetic interference between the 65 MHz MR signal, and the ultrasound signal by shielding the transducer and the extended connection cable with a copper foil and a double-coaxial copper jacket, respectively. The broadband acoustic noises generated inside the MR imager and picked up by the PEC were filtered by phase-lock amplifiers powered by a 9 V battery. In the last step, the optical digital output signal of the CTG's Doppler ultrasound monitor was detected by a photodiode. Its shaped electronic signal was fed into the analog ECG input of the imager.
MRI measurements were performed on 2 pregnant ewes carrying singleton fetuses in supine position. The fetuses were 115th gestational days old. The fetuses were chronically instrumented with a carotid catheter to measure the fetal heart frequency for the cardiac triggering. The fetal heart rate (FetHR) was recorded by newly developed MR compatible ultrasound transducer of the cardiotocograph (CTG). During MR imaging, the ewes were artificially ventilated. Initially scout images were obtained in axial, coronal and sagittal orientations with half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequences (TR 1080 ms, TE 55 ms, Flip angle 150°, FoV 400 mm). Retrospective fetal cardiac PW and CTG gating was used on a 1.5 T (Tesla) imager (Symphony®, Siemens AG, Erlangen) with an 4-element phased array body coil. For comparison with the CTG trigger, the fetal heart rate was also recorded by the pressure pulse wave (PW) from an implanted carotid catheter with attached pressure transducer as described in detail elsewhere (Yamamura et al. 2009). A parallel imaging based (GRAPPA) retrogated Cine-MRI sequence with the following scan parameters was used for images of the heart in short axis as well as in the four and two chamber view: TE 1.57 ms; TR 50.12 ms; TFE-Factor 12; FOV 380; flip angle 65°; slice thickness 5 mm; voxel size 2.2 x 1.5 x 6.0 mm; total scan time 11 s / slice with 25 - 30 cardiac phases depending on the fetal heart rate. Saturation bands were used to minimize fold-over artifacts in the phase-encode direction. Skin exposure to local heat generation by eddy currents and RF energy absorption in the shielded ultrasound probe and its cable were tested by two adult subjects (two of the authors) and was measured by using a MRI compatible thermometer.

Results
After removing all perturbing components of the CTG's ultrasonic sensor and replacing them with non magnetic material, the artifacts of the probe itself were reduced to a minimum. The newly designed transducer shows a smooth behavior again with a signal reduction of 80% in a depth of 20 mm. For both techniques, i.e. CTG and PW triggering, an adequate quantitative measurement was possible. Left-ventricular cardiac function parameters of the fetuses were measured form the short axis as well as from the four chamber views to assess the temporal left ventricular stroke volume and its derived ejection fraction **(Table 1)**.

MR-trigger	HR (min^{-1})	EDV (ml)	ESV (ml)	EF (%)	CO (l/min)
PW	127	6.6	3.8	42	0.4
CTG	133	7.0	2.3	67	0.6

With respect to fetal heart rate triggering, a more sensitive information can be obtained from the 1st derivative of the temporal stroke volume (Figure 4b). The resulting ventricular filling rate patterns are very similar indicating that the CTG is registering the fetal heart beat with the same precision as the reference PW trigger.The thickness of the septum and the LV wall were 0.9 cm and 0.8 cm in diastole and 1.0 cm und 1.3 cm in systole, respectively, in both techniques and no differences could be measured.
No local temperature increase was sensed by the two volunteers during cardiac function assessment using the CTG and the PW- trigger.



First differentiation of temporal stroke volume (= ventricular filling rate) from pulse wave (PW: dashed line) and CTG (solid line) gated cine-MRI of a sheep fetus.

Conclusion
The newly developed MR compatible cardiotocograph with its ultrasound transducer allowed a sufficient cardiac triggering of the fetal heart without artifacts during the whole study. The so obtained cardiac MR images were comparable and as sufficient as pulse wave triggered MR images. This is new device should be applicable on the human fetus as well.

Key words:
Magnetic Resonance Imaging, Ventricles, Pregnancy, Diagnosis