In-utero blood flow quantification by Phase-contrast MRI using a new triggering method: Comparison with Doppler Ultrasound measurements in a sheep model

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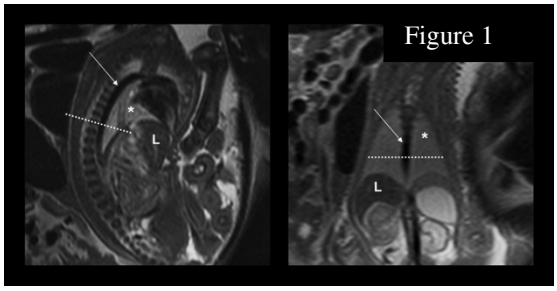
Introduction/Purpose

In fetal imaging considerable advances have been achieved in the last years. In addition to fetal ultrasound (US), which is still the diagnostic modality of choice, fetal magnetic resonance imaging (MRI) has gained substantial clinical relevance. The fetal MRI is considered as a valuable, complementary diagnostic tool in second and third trimester pregnancies and in cases of inconclusive prenatal ultrasound examination. Despite the advances in fetal MR imaging and the increasing implementation in clinical routine, imaging of the fetal heart and blood flow measurements remain a major challenge. Only recently, a MR compatible Doppler US device enabled noninvasive fetal cardiac triggering with cardiac volumetric assessments for the first time in a sheep model. However, prenatal blood flow quantification by MRI and validation of this method with standard US examination has not been performed so far. The aim of this study was therefore to demonstrate the feasibility of antenatal blood flow measurements using phase-contrast MRI (PC-MRI) in the fetal aorta for the first time by using a newly developed Doppler US device for triggering the fetal heart beat and to compare them with standard Doppler US measurements in a fetal sheep model.

Material and Methods

MRI on a 1.5 Tesla whole-body MR imager (Achieva, Philips Medical Systems) was performed on 4 pregnant ewes carrying singleton fetuses at gestational ages between 115 and 124 days. Prior to examination, the ewes were prepared with a venous catheter and were intubated after intravenous administration of anesthesia. A MR compatible US transducer (HP15245 A) of a standard CTG (Hewlett Packard) was used for fetal cardiac triggering. A laptop computer with novel beat recognition software processed the obtained electric signals by piezoelectric crystals. The derived trigger pulses were conducted to the ECG unit of the MR system and used to trigger the fetal heart beat. The transducer was placed on the abdominal wall of the maternal sheep, above the fetal heart, and fixed with a belt when a constant fetal heartbeat was received. Scout images of the fetal thorax were obtained using T2-weighted turbo spin-echo (TSE) sequences (TR 2900, TE 90ms, FA 90°, FOV 430mm, slice thickness 5mm, matrix size 512 x 512, TSE factor 30). Fetal PC-MRI was performed in the descending thoracic aorta (AoD). Blood flow measurements in the fetal AoD, in a plane perpendicular to the direction of blood flow, were planned referring to sagittal and coronal T2-weighted images (**Fig. 1**). Typical scan parameters of the applied retrospective through-plane 2D-cine phase-contrast angiography (GRE-) sequence were TR 4.5 ms, TE 2.9 ms, FOV 350 mm, FA 15°, slice thickness 8 mm, matrix size 224 x 224. Temporal resolution was 40 time frames per RR-interval using CTG gating as described above. Velocity-encoding sensitivity (VENC) was set to 100 cm/s to avoid phase aliasing. Mean examination time was 25 minutes. Within 30 minutes following MR examination US examinations with color and pulse-waved Doppler modes (3.3 MHz) were performed (GE Healthcare) and a convex curved-array transducer outside the MR unit. Blood flow measurements in the fetal AoD were performed in a sagittal view of the fetal aorta.

PC-MRI included quantitative flow analysis with calculation of peak and mean flow velocities. Stroke volume was calculated by integration of the area under the antegrade flow curve. For comparison of blood flow measurements obtained with PC-MR and Doppler US mean peak velocities and standard deviations (SD) were calculated. Differences between the PC-MR and Doppler US flow measurements were evaluated using paired t-test. Differences were considered significant for $p<0.05$.



Results

Fetal MRI: The cross-sectional lumen of the AoD could be clearly identified in all of the assessed magnitude and phase encoded images (**Fig. 2**). The endothelial border was strictly excluded from the ROI to prevent partial volume averaging near the vessel wall. Mean cross-sectional diameter of the AoD was 6.2 mm (SD ± 0.46). Time velocity curves demonstrated biphasic arterial waveforms with a strong early systolic peak and continuous positive diastolic blood flow (**Fig. 3**). The average peak flow velocity was 61.2 cm/s (SD ± 5.1). Average mean velocity and stroke volume were 27.8 cm/s (SD ± 4.8) and 3.75 ml (SD ± 0.3), respectively (Table 1).

Fetal US: Doppler US studies revealed biphasic arterial waveforms, demonstrating a strong systolic increase followed by continuously positive diastolic blood flow. Mean peak velocity was 62cm/s (SD ± 9.2) (Table 1). In three of the four fetal sheep Doppler US blood flow measurements were successfully performed. No significant difference was found between PC-MR and Doppler US flow measurements (peak flow velocities) (paired t-test: p=0.72).

	US	PC-MRI		
	Peak vel. [cm/s]	**Peak vel.** [cm/s]	**Mean vel.** [cm/s]	**SV** [ml]
Fetus 1	n.a.	61	27	3.4
Fetus 2	72	67.3	33.5	4.2
Fetus 3	54	54.9	25.4	3.7
Fetus 4	60	61.4	34.4	3.2
Mean ± SD	**62** ± 9.2	**61.2** ± 5.1	**27.8** ± 4.8	**3.75** ± 0.3

Table 1

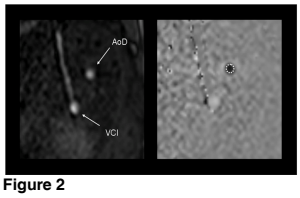


Figure 2

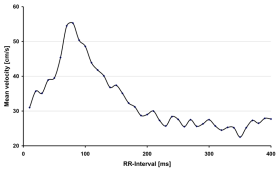


Figure 3

Conclusion

Phase-contrast MRI flow velocimetry of the fetal aorta was successfully performed using the newly developed MR-compatible Doppler-Ultrasound device for fetal cardiac triggering in a fetal sheep model. Comparison with fetal Doppler ultrasound revealed concordant results.

Key words:

Fetus, MRI, Ultrasound, Flow, Vessels