

## Abstract

Fetal cardiac magnetic-resonance imaging (CMRI) is limited by unpredictable fetal motion and lack of realistic motion phantoms for sequence development and gating validation, limiting its utility for diagnosing congenital heart disease (CHD) in utero[1][2]. Existing phantoms lack anatomic fidelity or fail to reproduce the magnetic-relaxation properties of fetal tissues, creating a gap in the ability to evaluate motion-compensation strategies under clinically relevant conditions[1]. The objective of this project was to design, fabricate, and validate a modular, MRI-compatible fetal-cardiac motion phantom that mimic the general geometry, mechanical behavior, and  $T_1/T_2$  relaxation characteristics of a 35-week gestation fetus within a maternal-uterine environment. A  $12 \times 9 \times 7$  in womb cavity is cast from an 8% w/v polyvinyl-alcohol (PVA) hydrogel, whose  $T_1 \approx 800$  ms and  $T_2 \approx 80$  ms at 1.5 T closely match in-utero soft tissue and preserve realistic image contrast[1]. The fetal torso and heart were 3D printed from PLA and positioned inside the cavity, the interstitial space is filled with 0.9% NaCl isotonic saline, whose relaxation times emulate amniotic fluid and provide appropriate susceptibility matching[1]. 3D printed wire loops from PLA are punctured into the placenta wall and PVA gel to anchor the model. Translational motion of 10 mm was produced by a low-pressure hydraulic actuator acting on a tethered string, while a custom rotational platform aims to generate  $15^\circ$  of yaw and pitch to replicate maternal drift and fetal kicking. All components are sealed with Parafilm and capped with a rigid plastic lid to maintain fluid integrity during testing.

The assembled system aims to satisfy design criteria for geometric fidelity, motion range, and MRI-compatible material properties, offering a repeatable platform for future CMRI sequence validation and algorithm development aimed at improving imaging of fetal CHD. Future work will include quantitative MR imaging of the phantom at 1.5 T and 3 T to assess SNR ratio, artifact behavior, and the fidelity of simulated fetal-heart flow. The phantom will incorporate anatomically accurate limbs and joints with embedded mechanical actuators that generate programmable jitter to simulate fetal limb and joint movements. Additionally, using machine learning to train on the acquired motion data to classify motion patterns and predict optimal gating and reconstruction parameters using the assembled system.

## References

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