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Team 11: Fetal Cardiac MRI Phantom for Fetal Motion Acquisition

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Background & Objectives

- FCMR offers complementary congenital heart diseases (CHD) diagnosis alongside ultrasound in 75/1,000 births.
- Unpredicted fetal motion causes up to 10 mm translation and 15° rotations, corrupting cine reconstructions and Dopple gating signal.

Problem: No validated fetal phantom exists to benchmark fetal MoCo (jerk, jitter, kick) algorithms repeatedly.

Objectives:

- Design and fabricate an MR-compatible fetal phantom of 34 weeks gestation motion.
- Implement hydraulic actuation producing controlled translation and rotation movement.
- Validate phantom motion performance against clinical FCMR acquisition sequences with acquisitions at 1.5T.

Prototype Design

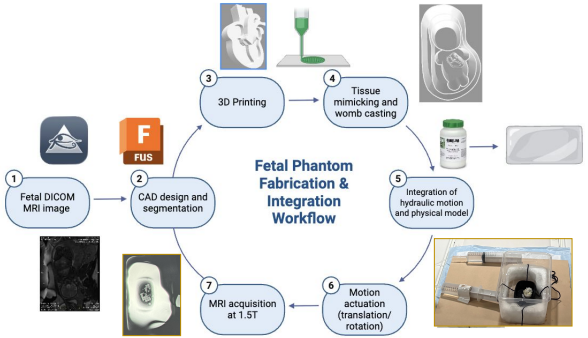


Figure 1. Fetal phantom for motion fabrication workflow from DICOM segmentation to 1.5T acquisition.

Subproject 1 & 2: CAD Design and Tissue Mimicking Components

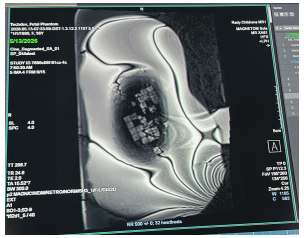
- DICOM segmentation
- 3D printing: PLA (rigid), TPU (flexible)
- Negative mold for PVA hydrogel casting into pear-shaped womb

Figure 2. (A) Fetal DICOM MRI scan, source for anatomical segmentation. (B) 3D-Printed PLA fetal heart. (C) TPU torso (attached fetal heart). (D) Assembled womb ready for PVA freeze-thaw cycling and isotonic fill.

Subproject 3: Simple Hydraulic Motion System

Figure 3. Visual Setup of the Hydraulic Motion System

Subproject 4: Motion Acquisition at 1.5T



Validation:

- Controlled displacement confirmed
- Motion remains consistent across cycle
- Banding artifacts

Figure 4. Cine Segmentation of Phantom using HASTE and SSFP sequences during 16 second Maternal Breathing Hold

Expected Outcomes

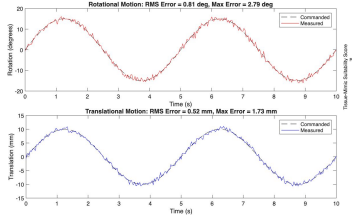


Figure 4. Controlled translation and rotational motion variability

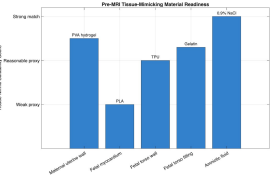


Figure 6. Anatomical Match of Phantom Tissue-Mimicking Materials

Future Directions

- Conduct quantitative MRI (1.5 T/3T) to distinguish T1/T2, signal-to-noise ratio (SNR), and artifact profile in relation to in-vivo fetal datasets
- Model limb and joint modules with anatomically accurate inserts with PVA-hydrogel casings to mimic fetal tissue elasticity and relaxation
- Integrate PID-controlled stepper motors for programmable translation and rotation

Acknowledgements & References

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References