An anthropomorphic MR phantom of the gravid abdomen including the uterus, placenta, fetus and fetal brain.

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Target audience: Researchers needing a realistic anthropomorphic pelvic phantom of a pregnant woman for coil and pulse sequence optimization as well as safety validation.

Purpose: To design and build an MRI phantom that mimics critical organs and typical fetal motion in pregnancy at 36-weeks of gestational age. The tissues of interest include the pregnant woman's torso, the uterus, the placenta, as well as the fetal brain and body. The phantom will facilitate MR sequence development, motion navigation, motion artifact estimation and mitigation, while simultaneously enabling safety evaluation.

Introduction: Fetal MRI is increasingly used in the examination of fetuses with high risk or ultrasound suspicion of anomalies as MRI provides higher soft tissue contrast. The most common indications for fetal MRI are neurological followed by the evaluation of suspicious thoracic masses. However, the accuracy of MRI is limited by the spatial resolution and image contrast achievable in the ~ 30 second time frame necessary to limit motion artifacts. Thus the development of MR acquisition methods insensitive to fetus movement is of paramount importance. Yet, as newer approaches are envisioned, it is important to fully test the method and validate safety before the novel approaches are attempted in highly vulnerable human fetuses. The best method to test novel advances is in an accurate phantom. To our knowledge no anthropomorphic pregnant woman phantom is available for this purpose.

Methods: A 36-week pregnant woman underwent MRI examination on a Siemens Skyra 3T scanner, after signed consent. The mother was placed head-first into the scanner lying on her left side. Two commercial receive only array coils were used to cover the gravid abdomen: an 18-element body flexible receive array coil placed anteriorly and a 12-element spine coil, which covered the posterior. A single shot axial HASTE sequence was used to reduce B0 effects and to obtain the images used for creating the 3D model of the pregnant woman and fetus. These images (192x192 pixels over 48cm FOV; slice-thickness 2.5mm; echo spacing 5.62ms, TE = 119ms, TR = 1.8s, partial Fourier of 5/8;GRAPPA acceleration factor of 2) were manually segmented using 3DSlicer[1] into 5 compartments: uterus, fetus brain, fetus body and placenta. Each segmented tissue class was then smoothed and, eroded and dilated to eliminate island effects. 3DSlicer allows exporting the segmented tissues in *.stl format, which contains the necessary meshes for the CAD design. Then, Meshlab[2] was used to decrease the mesh size (number of faces) and to smooth the final surfaces. These decimated and smoothed *.stl files were then imported into Rhinoceros 3D[3] to create the joints, sliders and groves for fitting the different compartment spaces together as well as filling spaces in which to pour the agar gel. The different compartments will be filled using the agar-based tissue-mimicking gels compositions in Table 1. Solutions approximating the T_1 and T_2 of woman torso, uterus, placenta, fetus body and brain were prepared from aqueous mixtures of Magnevist™ (Gd, r_1 = 3.1, r_2 = 3.7 $mM^{-1}s^{-1}$) and Ferumoxytol™ (Fe, r_1 = 7.5, r_2 = 92 $mM^{-1}s^{-1}$). Also a temperature contrast agent TMDOTMA and/or ethylene glycol will be added to evaluate the temperature rise resulting from SAR deposition[5]. The uterus compartment will be agar-free as in further versions of the phantom fetus movement will be added. A 3D printer Fortus 360mc with extended print area will fabricate the sections. Silicone sealant is needed to seal the halves of each compartment.

Tissue	NaCl [Weight %]	Conductivity (S/m)	T1/T2ms	[Gd] (mM)	[Fe](mM)
Woman Torso	0.27	0.72	726/95	0.1105	0.15868
Uterus	0.79	1.5	4000/2000	0	0
Placenta	0.62	1.24	1700/366	0.0545	0.02255
Fetus Body	0.27	0.72	583/92	0.2215	0.10391
Fetus Brain	0.09	0.45	977/101	0	0.10310

Table 1. Solutions and expected values for the different tissues

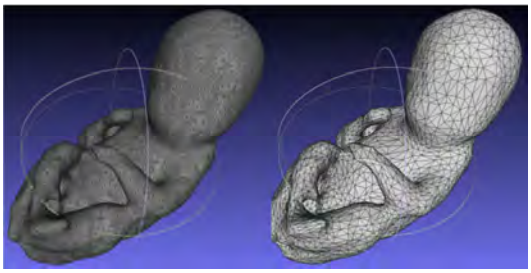

Fig. 2. – Decimation and smoothing of the fetus model.

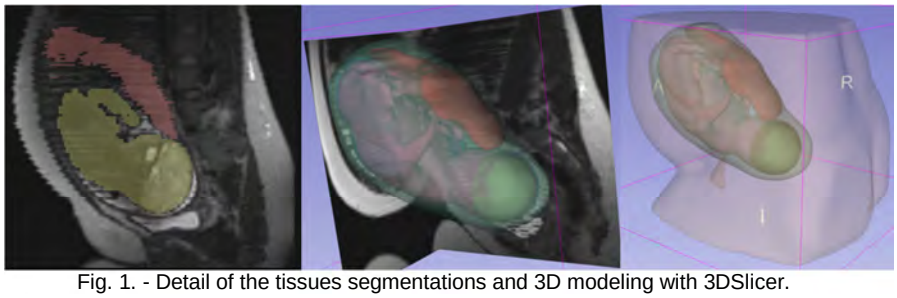

Fig. 1. - Detail of the tissues segmentations and 3D modeling with 3DSlicer.

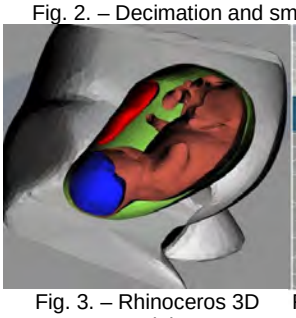

Fig. 3. – Rhinoceros 3D model.

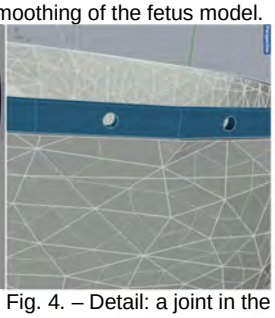

Fig. 4. – Detail: a joint in the uterus.

Results: Figure 1 shows the steps followed in 3DSlicer to obtain the meshes that are then smoothed and decimated (reduction of faces) using MeshLab (Figure 2). Figure 3 shows the 3D-pinter ready CAD files with all joint, groves and sliders for joining the different compartment together.

Discussion: We have designed a realistic anthropomorphic phantom of a 36-week pregnant woman phantom that includes only the basic tissues: uterus, placenta, fetus body and fetus brain, in order to minimize the number of plastic boundaries in the phantom. This phantom will be useful for validation of sequences and motion tracking approaches specifically designed for fetal imaging as well as SAR estimations and validations. This phantom will also be helpful for designing and bench testing of conformal coil arrays used for high resolution and high sensitivity fetal imaging.

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