

Hybrid 3D modeling of mother and fetus from medical imaging for dosimetry studies

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Purpose

Several organizations and institutes like the WHO (World Health Organization), the European Cooperation in the Field of Scientific and Technical Research (COST 281) or the MMF (Mobile Manufacturers Forum), have shown that the study of interactions between radio frequency waves and biological tissues needs precise models of the human body at various ages. Human head models have been already developed by our group for adults and children in order to study the impact of the use of a mobile phone on the head. With hand-free kits and the magnetic field exposure of some professionals, whole human body models and fetus models need to be created. Few models already exist but present several defects: they are incomplete or not representative or too much simplified [1-8]. Thus, the aim of our project is to model detailed, representative and realistic three dimensional pregnant women and their fetus at various stages of gestation and in different positions in order to simulate several radiation dosimetry studies. These models are created from the segmentation of medical imaging: ultrasound (US) and magnetic resonance imaging (MRI) for the fetus and from a synthetic woman model created with the software DAZ Studio (www.daz3d.com) for the mother.

Methods

The first step is to segment the tissues playing an important role in dosimetry such as the uterus, the brain or the bladder. This has been done either manually for a number of data sets, or automatically, using a method where statistical distributions of tissues are integrated in a deformable model [9]. On each mask, a triangulation method was applied on its surface in order to construct the corresponding mesh. Depending on the age of the embryo, we can segment on the US images: the embryo, the amniotic fluid, the umbilical cord, the trophoblast, the myometrium, the endometrium and the yolk sac. For the MRI data, a similar approach was used. However, due to the anisotropy of the images (the voxel size is typically $1 \times 1 \times 4 \text{ mm}^3$), staircase effects corrupted the generated surfaces of the segmented, which were not compatible with dosimetry computation. Indeed, the numerical algorithms used to estimate the propagation of electromagnetic waves and to infer the induced dosimetry require smooth and isotropic models. Hence, the segmented objects were filtered to reduce these staircase effects, using a simple Gaussian filter. Successive contours of the filtered segmented objects were then connected to obtain smooth triangulated meshes. Depending on the age of the fetus, the fetus and his eyes, brain, urinary bladder, lungs, heart can be segmented in MRI, along with uterus, amniotic fluid, and umbilical cord.

The field of view of the medical images used to extract the fetus included only a part of the mother body. In order to have a complete body, we use the software tool DAZ Studio that provides a virtual woman body which is deformable and can be placed in arbitrary posture. Using the software tool Blender, we then inserted the fetus in the virtual maternal body (see Figure 1). The virtual mother body was reshaped using a lattice based free form deformation, to fit the part of real mother body envelope included in the medical images. To guarantee that our models remained anatomically correct and depicted a realistic maternal body, all this deformation work was done with the control of obstetricians that validated our models. The uterus is generally located at about 2 cm from the subcutaneous interface of the mother and follows the shape of the spine. Half of the thickness of the non-gravid abdomen consists of the spine and vessels blood as the aorta. The head of the fetus is positioned on the line linking the pubis and the top of the sacrum. The feet of the fetus are generally under the D10 rib.

For dosimetry studies, we had to generate voxelized models. Each tissue type was assigned a unique label in order to create the final 3D images that contain all the segmented tissues. To avoid such artifacts at tissue

interfaces, corresponding to anatomical incoherencies such as open skulls or open uterus, we modified the tissues that contained other tissues by the union of the containing tissue and the dilating of the contents tissues. For example, we changed the uterus into the union of the uterus and the dilation of the fetus and the umbilical cord.

Results

We modeled so far four pregnant women with embryo segmented from US 3D images at 8, 9, 10 and 13 weeks of amenorrhea and five pregnant women with fetus segmented from MRI 3D images at 30, 32 (two models), 33 and 34 weeks of amenorrhea. All models were anatomically validated by obstetricians and pediatric radiographers. They include anatomical variations to represent several typical pregnancy configurations. In particular, the set of models includes: a fetus that is in breach position (see Figure 2). This position can have an impact on the dosimetry; filled maternal urinary bladder. It elevates the fetus position and can also change the dosimetry; model where the MRI was acquired with the mother in a lateral decubitus whereas the others were acquired in dorsal decubitus positions. This position changes the shape of the mother abdomen and also the fetus position.

These models are currently processed by other groups for simulated dosimetry measurements. The influence of the anatomical variability (e.g. the position, the urinary bladder filling, the fat thickness ...) will guide our future work for refining our current models and generating new ones.

Conclusion

We have proposed a new methodology to construct hybrid pregnant women models with detailed fetal anatomy (including several fetus and mother structures and tissues) extracted from MRI and US image data, combined with a woman body from a synthetic model. So far, we have created nine models at various stages of the gestation and in different positions. The placement of the fetus in the synthetic woman was performed under medical control. All our models were validated by clinical experts and anatomically corrected. Dosimetry studies with these models have already started and the first results are encouraging. These models will be made freely available to the scientific community, in a near future.

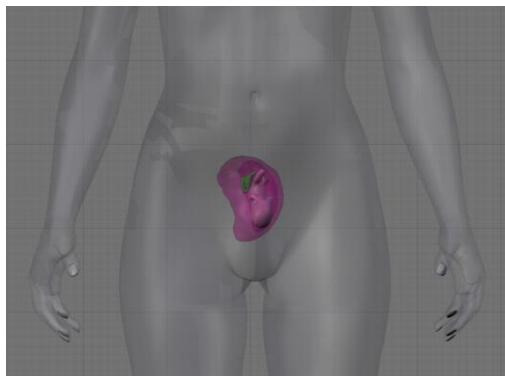


Figure 1: 3D model of fetus placed in the virtual mother

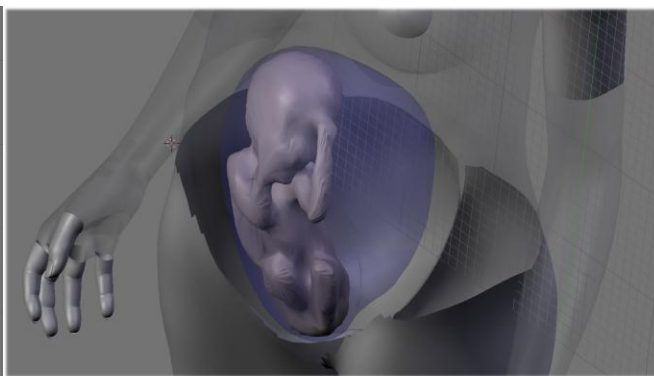


Figure 2: Fetus in breach position

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