# Dosimetry Studies on a Fetus Model Combining Medical Image Information and a Synthetic Woman Body


L. Bibin[1], J. Anquez[1], A. Hadjem[2], E. Angelini[1], J. Wiart[2] and I. Bloch[1]

[1] Institut Telecom, Telecom ParisTech, CNRS UMR 5141 LTCI, Paris, France
[2] France Telecom, Orange Labs R&D, Issy les Moulineaux, France



*Abstract*— **Wireless systems are increasingly used and the electromagnetic fields (EMF) generated by these systems have induced a large public concern regarding potential sanitary effects, in particular on children and fetus during pregnancy. Few works have been performed to analyze the fetus exposure but additional studies are still needed, based on precise anatomical models. In this paper, we propose a new method to assess the fetus exposure, based on realistic anatomical models built from 3D MRI images at different gestational ages. The whole body specific absorption rate (SAR) and the maximum SAR over 10 grams have been estimated using finite differences in time domain (FDTD) simulation methods for five fetuses at different ages. Results show that the local and the whole body SAR are lower in the fetus than in the mother and that they depend on position and morphology but not on gestational age.**



*Keywords*— **"Dosimetry", "3D Modeling", "Segmentation", "Fetus", "Medical Imaging".**


## I. Introduction

Nowadays, wireless systems are increasingly used. More than 3 billions of people are nowadays using worldwide GSM mobile phone and more and more people are using Wi-Fi systems. The electromagnetic fields (EMF) generated by these systems to communicate have induced a large public concern about potential sanitary effects. The World Health Organization (WHO) has set up in 1996 the EMF Project to promote and coordinate the worldwide research around this concern. In 2004, the WHO set up a workshop (Istanbul June 2004) dealing with the sensitivity of children to EMF. One of the outputs of the workshop led to the recommendation of improvements in dosimetry studies. Precise models of the human body are therefore needed, in particular children and pregnant woman models.

Human head models were previously developed by our group for adults [1] and children [2-3] in order to study the impact of the use of a mobile phone on the brain [4-6]. With new usages (e.g. body worn and hand-free kit) and permanent exposures in professional environment, fetal dosimetry needs to be investigated with more care. Up to now only few fetus models have been developed and all present several limitations, being incomplete, not representative or too much simplified.

The aim of this project is to analyze the specific absorption rate (SAR) induced by an incident EM plane wave in different fetuses with detailed, representative and realistic three-dimensional pregnant women models 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 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.

In this paper, after reviewing the state of the art, we describe the image database and the proposed methods to create the models. We then present visual illustrations of one generated model. Using these models and the well known finite difference in time domain (FDTD) simulation method, the SAR averaged over 10 g and the whole body averaged SAR of a pregnant woman and her fetus are assessed for a plane wave (vertical polarization) at 900 MHz. Our main contribution is to propose a set of five models, enabling for the first time the study of position influence on dosimetry.

## II. State of the art

Adult computational models used in dosimetry studies are built using whole body MRI data, acquired on volunteers. Acquiring such data on a pregnant woman is impossible for ethical reasons. Therefore, hybrid models are built, merging stylized models (modeled with surface equations), synthetic models (issued from the computer graphics community) and/or voxelized models (extracted from medical images).

The first published pregnant woman model was a stylized model [7]. Even if unrealistic, it was useful as computational power was limited at this time and obstetric medical imaging could not provide suitable data to build voxelized models.

Recently, the advent of fast acquisition imaging protocols usable in routine obstetrical screening allows gathering data imaging the whole fetus without motion artifact. In [8], a voxelized model was built from computerized tomography (CT) images. The fetus model was coarse due to large slice thickness (7 mm) and only the fetal soft tissues and skeleton were differentiated. The pregnant woman model was truncated, the CT image including only the patient torso. The hybrid model SILVY was built combining an MRI of a malformed fetus with the model of [8], adding legs, arms and head models from computer graphics to this model [9]. It was a realistic whole body model, but the fetus and uterus modeling remained coarse. The uterus and fetus stylized model of [10] was embedded in the non-pregnant model


O. Dössel and W.C. Schlegel (Eds.): WC 2009, IFMBE Proceedings 25/III, pp. 321–324, 2009.
www.springerlink.com

NAOMI. This embedding involved voxel editing of NAOMI which induced variations in organs shapes and volumes. A highly detailed and realistic mother model was obtained, but the uterus and fetus model remained highly simplified. In [11], a voxelized model of the uterus and fetus was embedded in a women computer-aided design model. Using this interesting approach, a set of pregnant woman models at each month of gestation was generated, scaling the uterus and fetus models. Due to the complexity of fetal organs growth, scaling seems however inappropriate. A complex hybrid model using the CT images presented in [8], the VIP-MAN model [12] and computer aided design models were proposed in [13]. Three models were built at 3, 6 and 9 months of pregnancy. Anatomical realism is difficult to evaluate because the model building process involves many components and few fetal tissues are distinguished. In [14], a uterus and fetus model is merged within a non gravid woman model. The former model is morphed using free form deformation, yielding an anatomically correct model.

Each model presents advantages and drawbacks, considering realism and anatomical details. As no whole body woman model is freely available, we have adopted the approach presented in [11]. We create a set of hybrid models, merging uterus and fetus models extracted from medical imaging data, and a virtual woman body. In contrast with [11], uterus and fetus models are extracted from different medical images and are all realistic. The proposed set of hybrid models enables for the first time the study of the influence of the fetus position and morphology on dosimetry.

## III. Image database

In collaboration with pediatric radiologists from the Saint Vincent de Paul hospital (Paris, France), a study [15] was performed to select the best suited MRI imaging protocols for the segmentation of the fetus and the mother. The quality criteria included: large field of view in order to image the whole uterus, good global contrast, good spatial resolution ($1\times1\times4$ mm$^3$), fast acquisition (less than 30 seconds) and low sensitivity to fetal movements artifacts.

The MRI acquisition protocols FIESTA (Fast Imaging Employing Steady state Acquisition) for the General Electric systems and True FISP (Fast Imaging with Steady state Precession) for the Siemens system were chosen, corresponding to the generic sequence SSFP (Steady State Free Precession).

Figure 1 shows an MRI image and the outline of the fetus. The database gathered so far contains 22 cases between 30 and 34 weeks of amenorrhea.

## IV. Models

### A. Segmentation

From the image database, we 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 the method described in [16]. An example of fetus segmentation on MRI data is shown in Figure 1.

Fig. 1 Fetus outline traced on a slice of a 3D MRI data set.

### B. 3D reconstruction

A triangulation method is applied on the segmented surfaces to construct corresponding shape meshes. The segmented organs were filtered using a simple Gaussian filter to reduce the staircase effects due to the anisotropy of the images. Reducing these effects provides surfaces better suited to the algorithms used for dosimetry computation.

Fig. 2 A 3D fetus placed in the deformed virtual woman body.

### C. Fetus placement in the virtual woman body

As the body of the mother is not entirely included in the field of view of the medical images, we use a synthetic virtual woman body distributed with the DAZ studio software.

To obtain a realistic pregnant model, the synthetic woman model is fitted to the external envelope of the real maternal anatomy that is partially visible on the medical imaging data. The virtual body is reshaped using a lattice based free-form deformation with the software tool Blender (www.blender.org). The fetus and its internal organs are inserted into the virtual body using anatomical landmarks such as the pelvis.

To guarantee that our models are anatomically correct and depict a realistic maternal body, all this deformation work was done with the control of obstetricians and pediatric radiographers.

We have modeled so far five pregnant women with fetus segmented from MRI 3D images at 30, 32 (two models), 33 and 34 weeks of amenorrhea. Figure 2 shows a surface reconstruction of a fetus in the deformed virtual mother body.

Our models include anatomical variations to represent several typical pregnancy configurations. In particular, the set of models includes:

- a fetus in breach position. This position can have an impact on the dosimetry;
- a filled mother urinary bladder. This configuration elevates the fetus position and can also change the dosimetry;
- a model where the MRI was acquired with the mother in a lateral decubitus position whereas the others were acquired in dorsal decubitus positions; This position changes the shape of the mother abdomen and also the fetus position.

For dosimetry studies, we generate voxelized models from the surface models. Each tissue type is assigned a unique label in order to create the final 3D volumes that contain all the segmented tissues (see Figure 3).

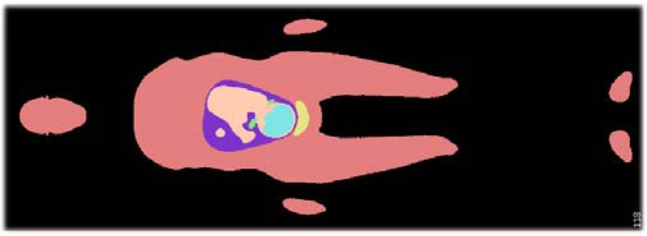

Fig. 3 3D Voxelized model of a mother and a fetus.

## V. Exposure analysis

### *A. Specific Absorption Rate assessment*

Using our models, we analyze the exposure of the fetus exposed to a plane wave.

The fetus is heterogeneous while the mother tissues are homogeneous. The dielectric properties of the fetus are those commonly used [17] while the dielectric properties of the mother tissue are those used in IEC [18].

The incident field at 900 MHz is vertically polarized and is arriving face to the pregnant women. The exposure is quantified by the well known (SAR) measure given by:

$$SAR = \frac{\sigma . E^2}{\rho} \qquad (1)$$

where $\sigma$ is the conductivity (S/m), $\rho$ the mass density (Kg/m3) and $E$ the rms electric field strength induced in tissues (V/m). In this study, the method used to assess electric field induced in the woman body is the finite difference in time domain (FDTD) [19]. To avoid spurious reflection at the boundary of the computational domain, we use the perfectly matched layer (PML) absorbing boundary conditions [20]. The exposure is characterized through the global SAR, averaged over the whole body and the local SAR averaged over 10 g of tissues. Most of the SAR studies that have been published are performed over a cube. To allow comparisons with previous studies, we decided to assess the maximum SAR over 10 g using a cube shape.

### *B. Results*

The whole body (wb) SAR and the maximum SAR over 10 grams have been estimated for 5 fetuses at different ages from 30 weeks to 34 weeks. Table 1 shows that the local SAR and whole body SAR are lower in the fetus than in the mother. The table shows also that the exposure does not increase with the age of the fetus but depends on the position of the fetus and the fetus morphology (see e.g. the results for the two models at 32 weeks, where the main difference between the data sets is the position and morphology of the fetus). The mean ratio of the whole body SAR between the fetus and the pregnant woman is 0.21 with a standard deviation of 0.062. This means that the whole body exposure in fetus is 5 times below the whole body exposure induced in the maternal model.

Table 1 SAR in the fetus and the pregnant woman

| Age (week) | 30 | 32 | 32 | 33 | 34.5 |
|---|---|---|---|---|---|
| SARwb (mW/kg/1W/m²) (fetus) | 1 | 1.6 | 2 | 1 | 1.1 |
| Ratio SAR wb (fetus / pregnant women) | 0.16 | 0.25 | 0.31 | 0.18 | 0.18 |
| Ratio SAR over 10g (fetus / pregnant women) | 0.026 | 0.028 | 0.042 | 0.033 | 0.025 |
| Maximum SAR over 10g (Fetus) mW/kg | 5.8 | 7.8 | 10.7 | 8.1 | 6.2 |

These results are in accordance with those obtained in [21, 22] for the fetus. For the woman, the results differ since we assumed homogeneous tissues, which was sufficient here since we were mainly interested in the ratio between SAR values in the fetus and in the woman. The maximum SAR values are interesting results too. This measure was not assessed before for the fetus, and is thus an additional contribution of the paper.

## VI. Conclusions

In this paper, we have presented a methodology to construct hybrid pregnant women models with detailed fetal anatomy extracted from MRI image data, combined with a woman body from a synthetic model. Our models are detailed as we can segment several fetal organs. For the moment, we have created five models from MRI images 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. These models will be made freely available to the scientific community, in a near future.

A comparison of SAR induced in a pregnant woman with different gestational stages was performed employing an incident plane wave having a vertical polarization and operating at 900 MHz. The SAR was numerically estimated using the FDTD method. The results show that the fetus exposure depends on the fetus morphology, fetus stages and on the position of the fetus, while it remains well below the local and whole body SAR of the mother. Further work is needed for definitive conclusion since these simulations have been carried out only for specific cases (specific fetus models and pregnant women with homogeneous tissues).

For fetus at earlier stages of gestation, we have already developed models issued from 3D ultrasound images [23], and simulations still be carried out on these models as well.

## Acknowledgment

This work has been partially founded by a grant from the Fondation Santé et Radiofréquences and by Orange Labs.

## References

1. Dokladal P, Bloch I, Couprie M, Ruijtersand D, Urtasun R, Garnero L (2003) Topologically Controlled Segmentation of 3DMagnetic Resonance Images of the Head by using Morphological Operators. Pattern Recognition, 36(10):2463-2478.
2. Burguet J, Bloch I (2004). Homotopic Labeling of Elements in a Tetrahedral Mesh for the Head Modeling. CIARP, Lecture Notes in Computer Science, Puebla, Mexico, 3287:566-573.
3. Burguet J, Gadi N, Bloch I (2004) Realistic Models of Children Heads from 3D MRI Segmentation and Tetrahedral Mesh Construction. 2nd International Symposium on 3D Data Processing, Visualization and Transmission, 3DPTV, Thessaloniki, Greece, 631-638.
4. Hadjem A, Lautru D, Dale C, Man Fai Wong, Hanna V F, Wiart J (2005) Study of specific absorption rate (SAR) induced in the two child head models and adult heads using a mobile phones IEEE Trans. Microw. Theory Tech. 53 4–11.
5. Wiart J, Hadjem A, Gadi N, Bloch I, Wong M F, Pradier A, Lautru D, Hanna V F, Dale C (2005) Modeling of RF exposure in children. Bioelectromagnetics 26:45–50.
6. Wiart J, Hadjem A, Wong M F, Bloch I (2008) Analysis of RF exposure in the head tissues of children and adults. Phys. Med. Biol. 53:3681–3695.
7. Stabin M G et al (1995) Mathematical Models and Specific Absorbed Fractions of Photon Energy in the Non pregnant Adult Females and at the End of Each Trimester of Pregnancy. Springfield, Va.: Oak Ridge National Laboratory; National Technical Information Service.
8. Shi C, Xu X G (2004) Development of a 30-week-pregnant female tomographic model from computed tomography (CT) images for Monte Carlo organ dose calculations. Medical Physics, 31:2491.
9. Cech R, Leitgeb N, Pediaditis M (2007) Fetal exposure to low frequency electric and magnetic fields. Physics in Medicine and Biology, 52(4):879-888.
10. Chen J (2004) Mathematical models of the embryo and fetus for use in radiological protection. Health Physics, 86(3):285–295.
11. Wu D, Shamsi S, Chen J, Kainz W (2006) Evaluations of Specific Absorption Rate and Temperature Increase Within Pregnant Female Models in Magnetic Resonance Imaging Birdcage Coils. IEEE Transactions on Microwave Theory and Techniques, 54(12):4472–4478.
12. Xu X G, Chao T C, Bozkurt A(2000) VIP-MAN: an image-based whole-body adult male model constructed from color photographs of the visible man project for multi-particle Monte Carlo calculations. Health Physics, 78(5):476.
13. Xu X G, Taranenko V, Zhang J, Shi C (2007) A boundary-representation method for designing wholebody radiation dosimetry models: pregnant females at the ends of three gestational periods-P3,-P6 and-P9. Physics in Medicine and Biology, 52(23):7023–7044.
14. Nagaoka T, Togashi T, Saito K, Takahashi M, Ito K, Watanabe S (2007) An anatomically realistic whole-body pregnant-woman model and specific absorption rates for pregnant-woman exposure to electromagnetic plane waves from 10 MHz to 2 GHz. Physics in Medicine and Biology, 52(22):6731-6745.
15. Anquez J, Angelini E, Bloch I, Merzoug V, Bellaiche-Millischer A E, and Adamsbaum C (2007) Interest of the Steady State Free Precession (SSFP) Sequence for 3D Modeling of the Whole Fetus. In Engineering in Medicine and Biology Conference, EMBC 2007, pages 771-774, Lyon, France.
16. Anquez J, Angelini E, Bloch I (2009) Automatic segmentation of head structures on fetal MRI. In IEEE International Symposium on Biomedical Imaging (ISBI'09) (submitted).
17. Gabriel C (1996) Compilation of the dielectric properties of body tissues at RF and microwave frequencies Brooks Air Force Technical Report AL/OE-TR-1996-0037.
18. IEC 2005 Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices—Human models, instrumentation, and procedures: Part 1. Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz) Standard Int. Electrotechnical Commission (IEC) Std 62209-1.
19. Taflove A, Hagness S (2000) Computational Electrodynamics (Boston, MA: Artech House).
20. Berenger J P (1994) A perfectly matched layer for the absorption of electromagneticwaves J. Comput. Phys. 4 185–200.
21. Nagaoka T. et al. (2008) Postured voxel-based human models for electromagnetic dosimetry, Phys. Med. Biol,. 53:7047-7061.
22. Togashi T., Nagaoka T., Kikuchi S., Saito K., Watanabe S, Takahashi M., Ito K. (2008) FDTD Calculations of Specific Absorption Rate in Fetus Caused by ElectromagneticWaves From Mobile Radio Terminal Using Pregnant Woman Model, IEEE Transactions on Microwave Theory and Techniques 56(2):554-559.
23. Bibin L, Anquez J, Angelini A, Bloch I (2009) Hybrid 3D modeling of mother and fetus from medical imaging for dosimetry studies. CARS, 23rd International Congress and Exhibition, Berlin, Germany.

Author: Lazar Bibin
Institute: Telecom ParisTech, CNRS UMR 5141 LTCI
Street: 46, rue Barrault 75634
City: Paris Cedex 13
Country: France
Email: lazar.bibin@telecom-paristech.fr