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Electromagnetic fields: from dosimetry to human health

Simplified pregnant woman models for the fetus exposure assessment

Utilisation de modèles de femmes enceintes simplifiés pour analyser l'exposition du fœtus

Marjorie Jala [a,b,*], Emmanuelle Conil [a], Nadège Varsier [a], Joe Wiart [a], Abdelhamid Hadjem [a], Éric Moulines [b], Céline Lévy-Leduc [b]

[a] *Orange Labs and Whist Lab, 38–40, rue du Général-Leclerc, 92794 Issy-les-Moulineaux, France*
[b] *CNRS/LTCI/Télécom ParisTech, 37–39, rue Dareau, 75014 Paris, France*

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ABSTRACT

In this paper, we introduce a study that we carried out in order to validate the use of a simplified pregnant woman model for the assessment of the fetus exposure to radio frequency waves. This simplified model, based on the use of a homogeneous tissue to replace most of the inner organs of the virtual mother, would allow us to deal with many issues that are raised because of the lack of pregnant woman models for numerical dosimetry. Using specific absorption rate comparisons, we show that this model could be used to estimate the fetus exposure to plane waves.

RÉSUMÉ

Dans cet article, nous présentons une étude destinée à valider l'utilisation d'un modèle simplifié de femme enceinte pour analyser l'exposition aux ondes radiofréquences du fœtus. Ce modèle simplifié, construit en remplaçant la plupart des organes internes de la mère par un tissu homogène, nous permettrait de nous affranchir de plusieurs problèmes qui se posent avec les rares modèles de femme enceinte dont nous disposons pour la dosimétrie numérique. En comparant des debits d'absorption spécifique, on montre que l'utilisation d'un modèle semi-homogène est pertinente pour l'estimation de l'exposition du fœtus à une onde plane.

1. Introduction

In numerical dosimetry, assessing the exposure to radio frequency (RF) waves of fetuses throughout their development is quite a complicated issue. Currently, very few pregnant woman models are available, and most of them are non-pregnant heterogeneous woman models in which a fetus has been inserted. To our knowledge, whole-body pregnant woman models do not exist as there are no magnetic resonance imaging data that could be used to build them.

However, we do have those data for fetuses, and some models at various development stages have been made. Inserting those fetuses in non-pregnant heterogeneous models is possible, but not entirely satisfying, because of the uncertainty on visceral tissues positioning and quantity. Indeed, deforming the mother's organs to reach a realistic configuration is not easy. Furthermore, for the same deformation issues, the fetus could not be moved in those cases. Consequently, the resulting

* Corresponding author at: Orange Labs and Whist Lab, 38–40, rue du Général-Leclerc, 92794 Issy-les-Moulineaux, France.
E-mail address: marjorie.jala@telecom-paristech.fr (M. Jala).

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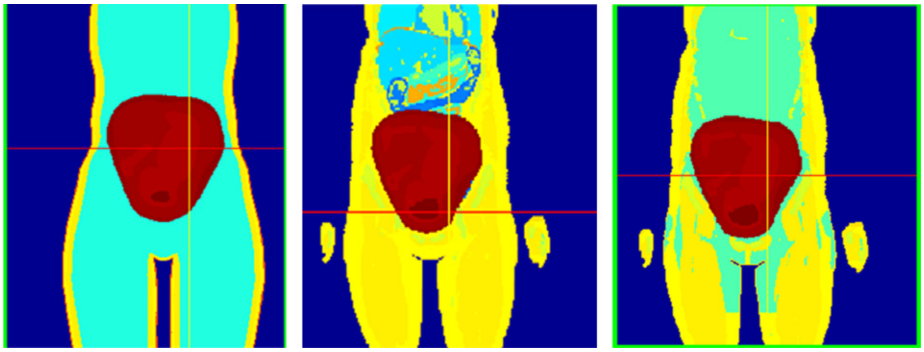


(a) (b) (c)

Fig. 1. (a) Pregnant augmented synthetic model, (b) heterogeneous Japanese model, (c) homogeneous Japanese model.

pregnant woman models could be considered restrictive because they would not be able to represent the variability that exists in reality; this variability must all the more be taken into account since it has been shown in [1,2] and [3] that morphology and posture of the mother and fetus (and the position and the type of the wireless device) have a high influence on the exposure.

To (partially) tackle with those issues and, as a consequence, to be able to carry out numerical dosimetry studies about fetus exposure from a statistical point of view, we propose to use a simplified non-pregnant woman model in which fetuses could be easily inserted and moved. The simplification consists in homogenizing most of the mother's tissues, and keeping differentiated the skin, the subcutaneous fat, the muscles and the bones, in the area where the fetus grows. So our aim is to validate the relevance of this model for numerical dosimetry experiments.

2. A description of pregnant woman models

In this section, we introduce the simplified model we aim at using, and the reference model that is used for the validation.

2.1. Augmented synthetic model

The simplified pregnant woman model which has to be validated is based on a synthetic non-pregnant woman model named Victoria and distributed by DAZ 3D Studio.[1] This synthetic woman model is completed by the tissues which seem more relevant to the point of view of fetus exposure to RF waves: one layer of skin, one layer of subcutaneous fat, one layer of muscles and finally the bones. All other tissues are replaced by a homogeneous one, whose dielectric properties are to be determined.

In this augmented synthetic model, 16 fetuses from 8 to 35 weeks of amenorrhea can be inserted, or, more precisely, 16 utero placento foetal unities (UPFU). Those UPFU are available thanks to the FEMONUM[2] and FETUS[3] projects. One UPFU is composed of the uterine wall, the amniotic fluid, the placenta, the umbilical cord, and the fetus, who may have some of his tissues differentiated (such as the brain, the spinal cord, the heart, the eyes, and the lungs).

Using such a model offers various advantages. On the one hand, thanks to the homogenization of the tissues surrounding the UPFU, the deformation of the mother's visceral tissues when inserting the UPFU and when moving the fetus is no longer a problem. On the other hand, the thickness of the subcutaneous fat and the muscle layers can be modified, so hopefully it will be possible to analyse the influence of the variability due to the morphology of the mother on the fetus exposure.

The augmented synthetic model, in which the same fetus as in the standard heterogeneous model (described in the following) has been inserted, is displayed in Fig. 1(a).

2.2. Standard heterogeneous model and semi-homogeneous model

In order to determine the dielectric properties of the augmented synthetic mother, and to confirm that the use of a semi-homogeneous model is relevant in the field of numerical dosimetry, the heterogeneous Japanese pregnant woman model is to be used as a point of reference. This model has been designed by Nagaoka et al. [4] by inserting a 26-week-old fetus in the non-pregnant heterogeneous Japanese woman model introduced in [5] (see Fig. 1(b)).

The Japanese heterogeneous pregnant woman model is to be homogenized (see Fig. 1(c)), so the characteristics to apply to the tissues of the augmented synthetic model would be known. The dielectric properties of the tissues are given by the

[1] http://www.daz3d.com/shop/.
[2] http://femonum.telecom-paristech.fr/index.html.
[3] http://whist.institut-telecom.fr/fetus.

Table 1
Proportion of the mother's tissues loaded in a small area around the UPFU.

Tissue	Proportion
Diaphragm (muscle)	0.0682
Bladder	0.0061
Colon	0.0427
Duodenum	0.017
Kidney	0.0234
Liver	0.0013
Ovary	0.0057
Small intestine	0.0332
Cartilage	0.0165
Fat	0.7973
Nerve	0.0039

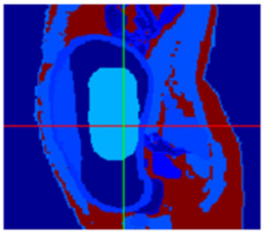


Fig. 2. Area around the UPFU where the tissue for homogenization are taken into account.

Table 2
Dielectric properties of the homogeneous tissue.

Frequency	Permittivity	Conductivity
900 MHz	15.4	0.28
1800 MHz	14.8	0.40
2100 MHz	14.6	0.45
2400 MHz	14.5	0.50

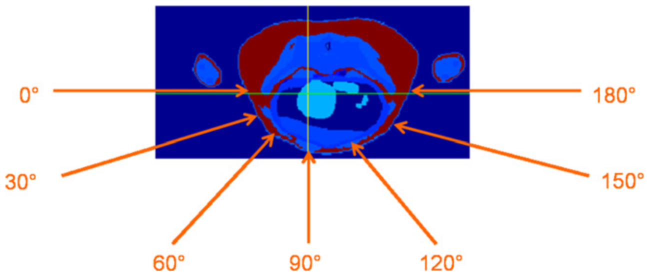


Fig. 3. Directions of arrival for the incident plane wave in the horizontal plane.

algebraic means of the permittivities and the conductivities of the tissues surrounding the UPFU, excluding the skin, the subcutaneous fat, the muscles and the bones (see Table 1). As we are interested in the fetus exposure, we assume that only the tissues located in a small area around the UPFU need to be taken into account (see Fig. 2). The dielectric properties of the homogeneous tissue for the frequencies used in the sequel are displayed in Table 2.

3. Influence of homogenization on fetus exposure

In this section, we shall compare the heterogeneous Japanese model to its semi-homogeneous counterpart in terms of exposure induced in the fetus; this is the first step in the process of validation of the use of a simplified model, and for the moment we do not consider the augmented synthetic model that we aim at using in the end.

The original heterogeneous model and the semi-homogeneous model are to be exposed to plane waves with vertical polarization. Seven angles of arrival are considered (see Fig. 3), and the experiment is repeated at 900, 1800, 2100 and 2400 MHz.

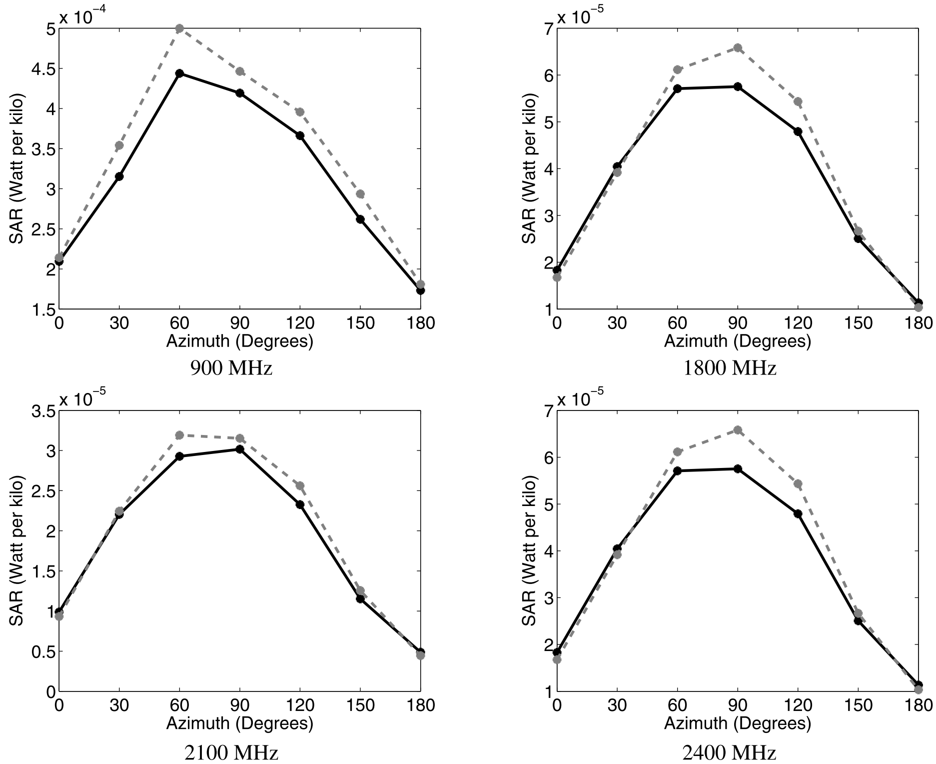


Fig. 4. Average whole-body SAR in the fetus according to the direction of arrival of the incident wave (gray dotted line: heterogeneous model; black plain line: semi-homogeneous model).

The exposure induced in the fetus is quantified by the whole-body specific absorption rate (SAR), expressed in watt per kilogram. The SAR calculation is performed through a home-made code that relies on the finite-difference time-domain (FDTD) method, an approach widely adopted in the field of numerical dosimetry.

The results are displayed in Fig. 4. We notice a good agreement between the values obtained for the heterogeneous model and for the semi-homogeneous one; actually, no more than a 15% difference is observed for all the experiments, which allows us to conclude that the use of a semi-homogeneous model is relevant in order to assess the fetus exposure. Those results show that the use of a semi-homogeneous model is relevant for the evaluation of the fetus exposure to plane waves. Now we aim at recreating the results obtained with the Japanese model by using the augmented synthetic model.

4. Exposure of the Japanese fetus inserted in augmented synthetic model

As we said before, our goal is to validate the use of the augmented synthetic model for numerical dosimetry. So we inserted the 26-week fetus from the Japanese model into the augmented synthetic model in order to see if we were able to obtain similar results. However, as it can be seen in Fig. 1, the augmented synthetic model and the Japanese pregnant woman model have very different morphologies, in particular in the area of the hips. So, in order to compare the results obtained for the two models, we are going to use an enlarged augmented synthetic model; this new enlarged model, displayed in Fig. 5, has been made by applying morphing techniques (see [3]) to the original synthetic augmented model.

This new model is exposed to plane waves in the same conditions as the Japanese pregnant woman model, applying the same dielectric properties to the tissues (see Section 3). The results are displayed in Fig. 6.

The behavior is globally similar for synthetic model and Japanese models, except for a singular behavior observed for the azimuth 0 degree (for the frequencies 1800, 2100, and 2400 MHz). The exposure levels are different too: if we compare Fig. 4 and Fig. 6, we denote that the average whole-body SAR in the fetus is lower with the synthetic model.

More investigations are necessary to explain those results. As there are very few homogeneous tissues for the incident wave to cross at the angle that we perform the SAR calculation, we can think that the inner morphologies of the semi-homogeneous Japanese model and the augmented synthetic model might be the source of those differences. Indeed, as it is displayed in Fig. 7, in the Japanese model there is not a continuous layer of muscle; so modifying the thickness of this layer in the augmented synthetic model might help to improve the results. The fat layer might need to be thicker on the sides of the augmented synthetic model, too.

Fig. 5. Enlarged augmented synthetic model.

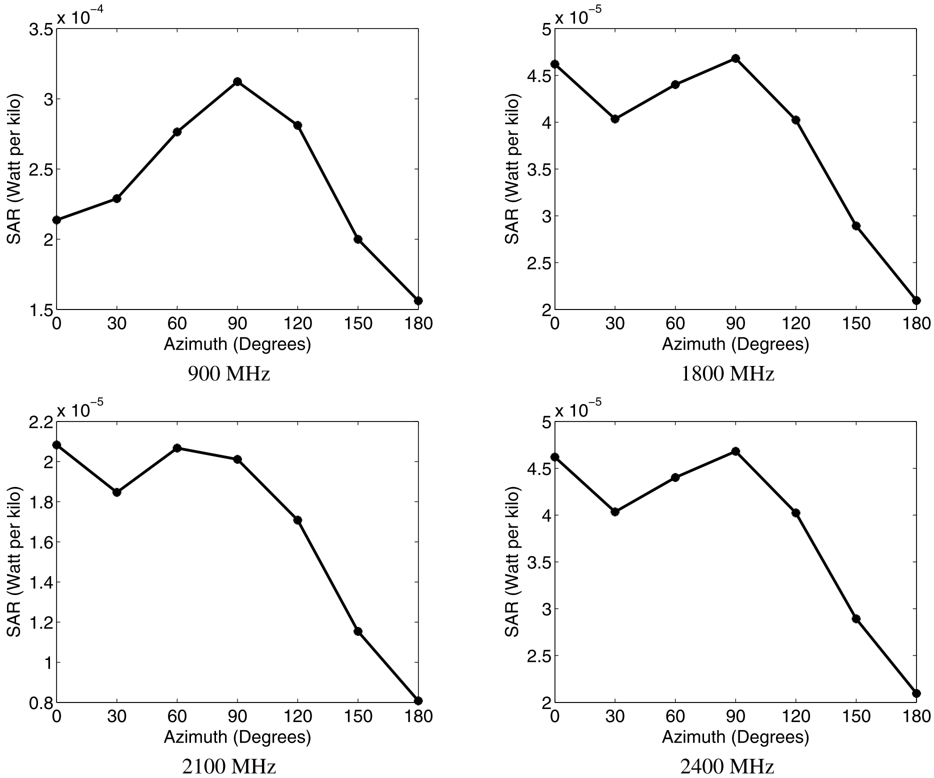


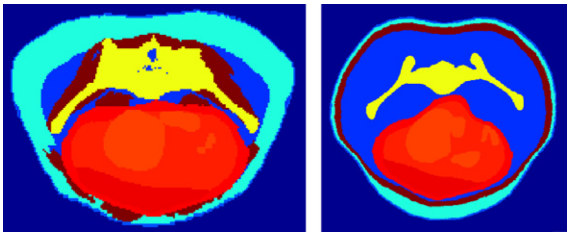
Fig. 6. Average whole-body SAR in the fetus according to the direction of arrival of the incident wave for the augmented synthetic model.

5. Conclusion and future works

In this paper, we have showed that the use of a semi-heterogeneous model is relevant for the evaluation of the fetus exposure to plane waves.

Nevertheless, we did not fully succeed in recreating the results obtained with the Japanese (heterogeneous and semi-homogeneous) models by using the augmented synthetic model. We have seen that the inner morphologies of the two mother models are quite different, and we plan to continue to modify the augmented synthetic model with morphing techniques to make it closer to the Japanese one, in order to get similar values of whole-body SAR in the fetus when using augmented synthetic model.

In any case, our aim is not to replace the Japanese model by another model that would lead to exactly the same results for the whole-body SAR in the fetus. What we mean to do is to show that the augmented synthetic model could correspond



(a) (b)

Fig. 7. (a) Semi-homogeneous model. (b) Augmented synthetic model. Fat layer is in cyan and muscle are in brown. For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.

to a wide variety of realistic models, if we modify its extern morphology (by using morphing techniques) and/or its inner morphology (by changing the thickness of the fat and/or muscle layer, and/or the dielectric properties of the homogeneous tissue), and if we insert into it other fetus models that could be moved inside the mother model. Thus, the augmented synthetic model would be used to analyze the variability of the fetus exposure with respect to all those parameters through a statistical study.

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