SAR Evaluation of Whole-body Pregnant Woman Models at Different Gestational Stage and Position in MRI Birdcage Coil

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Introduction:

Regulatory committees [1] have developed whole body average SAR limits to ensure that human subjects do not absorb excessive RF energy that may induce hazardous body temperature rise. However, the applicability of these limits is only for adults. It is not clear if the same limits can be used for pregnant women, fetuses, and, children. Previous studies [2-5] show some contradictory results because they adopted truncated body models [2,3] or anatomically simple geometries [4,5] to define the fetus. These approximations have resulted in potential uncertainties in the SAR evaluation. It is also clear that whole-body pregnant woman models at different gestational stages and positions should be adopted to evaluate the SAR variation at different field strengths in MRI. This paper describes the application of a set of pregnant woman models at different positions to calculate the SAR at 64MHz (1.5T) and 128MHz (3.0T), respectively.

Method:

This study has adopted three pregnant woman models, which represent the gestational stage at the end of 3, 6, and, 9 months, respectively [6]. The original sizes of the data sets were 542x290x1631, 546x381x1631 and 553x420x1633, respectively, at 1mm^3 isometric voxel resolution with 36 tissue types. They were resampled and adapted to commercially available finite-difference time-domain software SEMCAD (SPEAG; Zurich, Switzerland). A Four-Cole-Cole extrapolation technique was used to determine values for the dielectric properties of the tissues at different frequencies. Because of the age effect, the tissue dielectric properties of fetus were extrapolated from previous studies [7,8]. For this study, a 16-rung body size high-pass birdcage coil (610 mm coil diameter and 620 mm length, 660 mm shield diameter and 1220 mm length, as in a typical product coil) was modeled at 64MHz and 128MHz. The pregnant woman model back was 170mm away from the coil rung when considering the patient table. Two positions were adopted to investigate its effect on SAR distribution: heart and navel in the middle of the coil. The geometry of the coil and body are shown in Fig.1. With the acceleration hardware support (CIB 1000, SPEAG; Zurich, Switzerland), the human model and the coil were meshed at more than 45 million voxels and the running time is less than 5 hours for each calculation. The coil was driven in ideal case which means 32 current sources were placed in the end-ring elements with 22.5º phase-shift between each adjacent rungs. This method has shown practically identical results of driving the coil on resonance in quadrature at either two or four locations up to 128MHz [9].

Results & Discussion:

Results were normalized to whole body average SAR=2 W/kg (normal mode)[1]. The local SAR1c (one cell), SAR_{1g} and SAR_{10g} were calculated subsequently. Since the pregnant woman models have different weights, organ shapes, positions, and, fetus sizes at different stages, the absorption power and local SAR have obvious differences. With the increase of fetus size and the growth procedure at gestational phase of 3, 6, and 9 months, the belly becomes closer to the coil rungs and end-ring, which may bring potential safety concern. The high-conductivity amniotic fluid ($\sigma \approx 2.15$ S/m) surrounding the fetus can increase the power absorption as well. Therefore, higher SAR can be noticed in the liquid and partial fetal soft tissue. The SAR distributions on the central sagittal and coronal plane are shown in Fig.2 and Fig.3. The detail SAR comparison of fetus tissue is listed in Table I. It is interesting to observe that the SAR values at 3T are lower than those at 1.5T. This is probably the normalization method effect. In high-pass birdcage coil, the maximum SAR_{1g} and SAR_{10g} are in the exposure limits whether the heart or navel of the pregnant woman locates in the middle of the coil at both gestational stage of P3 and P6. And the fetal soft tissue SAR exceeds the exposure limit at gestational stage of P9 which correlated with our prediction. However, that is not always true for other birdcage coils, i.e., low-pass and band-pass types [2]. On the other hand, the fetus maximum local SAR increases along with the gestational stage. It is likely the increase of fetus size and amniotic fluid volume.

Reference:

[1]IEC 60601-2-33, 2006-02; [2]D. Wu *et al*, IEEE MTT, 2006;54:4472-4478; [3]J.W. Hand *et al*, MRM, 2006;55:883-893; [4]W. Kainz *et al*, Phys. Med. Biol.,2003;48:2551-2560; [5]P. Dimbylow, Phys. Med. Biol.,2006;2383-2394; [6]X.G.Xu *et al*, Phys. Med. Biol.,2007;7023–7044; [7] Y. Lu *et al*, Bioelectromagnetics,1996;17:425-426;[8] J. Wang *et al*, IEEE EMC,2006;48:406-413; [9]W. Liu *et al*. Appl. Mag. Res. 2005;29:5-18

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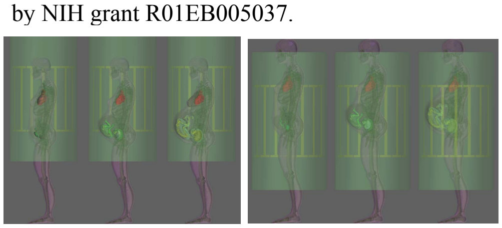
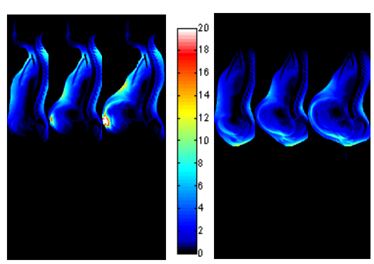


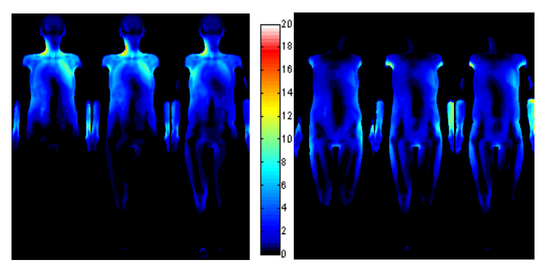
[A] [B]

Fig.1. Coil geometry and pregnant woman at different position(Heart[A] and Navel[B] in the middle of the coil) with three gestational stage:3 months(P3, left), 6 months(P6 middle) and 9 months(P9 right)



[A] [B]

Fig.2. SAR1g distribution(64MHz) of central sagittal plane at different position (Heart[A] and Navel[B] in the middle of the coil)of three models:P3, P6 and P9



[A] [B]

Fig.3. SAR10g distribution(128MHz) of central coronal plane at different position (Heart[A] and Navel[B] in the middle of the coil)of three models:P3, P6 and P9, respectively(from left to right)

Table I: Maximum SAR(W/Kg) of fetus tissue at different position, gestational stage, and field strength(normalized to whole body average SAR=2W/Kg).

		P3		P6			P9				P3		P6			P9		
Heart in the middle		Brain	Soft	Brain	Skeleton	Soft	Brain	Skeleton	Soft	Navel in the middle	Brain	Soft	Brain	Skeleton	Soft	Brain	Skeleton	Soft
	SAR1c	0.22	0.73	0.54	1.04	12.24	0.87	4.87	39.31	SAR1c	2.31	3.16	4.29	1.07	7.31	18.52	4.10	17.57
	SAR1g	0.21	0.59	0.33	0.71	8.88	0.39	3.05	28.50	SAR1g	1.94	2.73	2.80	0.69	4.93	4.52	2.53	10.92
1.5T	SAR10g	0.19	0.52	0.27	0.48	7.30	0.29	2.13	22.21	SAR10g	1.49	2.07	2.37	0.46	4.23	3.51	1.89	9.43
	SAR1c	0.09	0.33	0.28	0.33	3.65	1.43	1.57	15.32	SAR1c	1.42	1.95	1.97	0.52	4.95	9.59	2.00	9.29
	SAR1g	0.08	0.28	0.18	0.21	2.91	0.73	1.00	11.58	SAR1g	1.16	1.64	1.55	0.37	3.54	2.62	1.25	6.41
3.0T	SAR10g	0.07	0.17	0.14	0.15	2.33	0.63	0.74	8.73	SAR10g	0.87	1.23	1.31	0.24	2.79	2.16	0.93	5.48