Local SAR in High Pass Birdcage and TEM Body Coils for Human Body Models at 3T

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Introduction: The high pass birdcage (HPBC) coil is commonly used as a body coil for homogeneous excitation. The transverse electromagnetic (TEM) volume coil is increasingly utilized in MRI because of its high efficiency at high frequencies, and, is often used in parallel transmit systems. International standards have set safety limits on local and whole body/ head average specific absorption rate (SAR). *In vivo* measurement of local SAR is very challenging and thus many studies still rely on EM numerical simulations to understand local SAR under different conditions. In this work, the numerically computed local SAR of 4 human body models (HBMs) in 3 landmark positions were compared for 16-rung high-pass birdcage (HPBC) and TEM body coils at 3T.

Methods: A TEM body coil of diameter 61.0cm was modeled with 16 copper rungs attached to a copper shield of (dia=65.0cm, length=100.0cm) via copper strips (2.5cm×2.0cm). Each TEM rung was 2.5cm wide, 42.2cm long, and, had four capacitor junctions. The 16-rung HPBC body coil was 61.0cm in diameter and 62.0cm long and is shielded by a copper shield of diameter 66.0cm and 122.0cm in length. The coils' dimensions were based on typical product body coil dimensions. The coils were excited in the ideal case where current sources with identical currents (4A sinusoidal continuous wave at 127.74 MHz) and azimuthally dependent phases (22.5° apart in adjacent rungs) replaced all capacitors [1]. A total of 64 and 32 current sources were used in the TEM and HPBC coils, respectively. The visible man (scaled), visible woman [2], NORMAN, and, NAOMI [3,4] human body models, with 23, 34, 37, and, 40 tissue types, respectively, were used in the experiments. The HBMs were positioned with their heads, hearts, and, pelvises in the center of the coil rungs (Fig. 1), and, remeshed to a finite-difference time-domain (FDTD) cell size of 3mm×3mm×3mm. A Liao absorption boundary condition was used for all simulations. The back of each HBM located 17.5cm away from the furthest rung in the posterior direction. A 4-Cole-Cole extrapolation method was used to compute the dielectric properties of the various tissue types. Twenty-four simulations were performed (4 HBMs×3 landmark locations×2 body coils). After each simulation, the whole body average SAR was normalized to the IEC limit [5] of 2 W/kg and the resultant maximum local SAR values, averaged over 10g (SAR_{10g}) regions, were tabulated (Table 1). All numerical FDTD simulations (1.75 hour each) were performed with the commercial software xFDTD (Remcom, State College, PA) on an Intel Xeon quad-core 2.13 GHz CPU.

Results and Discussion: The SAR to whole body average SAR ratios in Table 1 showed that local SAR may vary significantly with different human body types and positions. For any given landmark position and coil type, the different tissue morphology, body mass, structure, hand-position, and, tissue types across all HBMs led to very different local SAR values. For example, the NAOMI model consistently had the highest SAR_{10g} values for most of the simulations because, among all HBMs, her hands were closest to the rungs. There was no evidence to suggest that the TEM or HPBC coil consistently yielded worse local SAR values across all HBMs. This was notable because it highlighted the strong dependence of SAR on the human body model parameters and made any generalization of local SAR differences between the two coils a risky proposition for safety evaluation purposes. The slices with the maximum SAR_{10g} in the axial and coronal planes are shown in Figs.2-3.

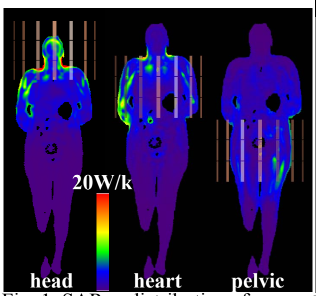

Fig. 1. SAR_{10g} distributions for visible woman model in TEM coil at 3 landmark positions.

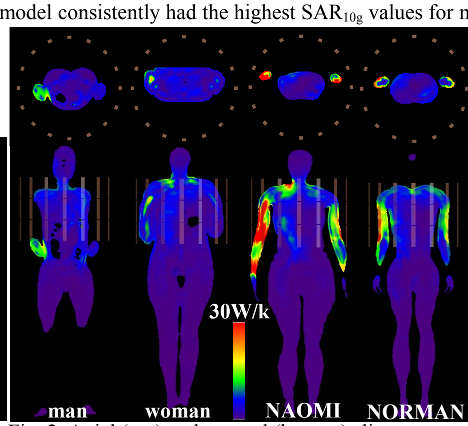

Fig. 2. Axial (top) and coronal (bottom) slices showing maximum SAR_{10g} for HBMs in **TEM** coil at heart-centered landmark position.

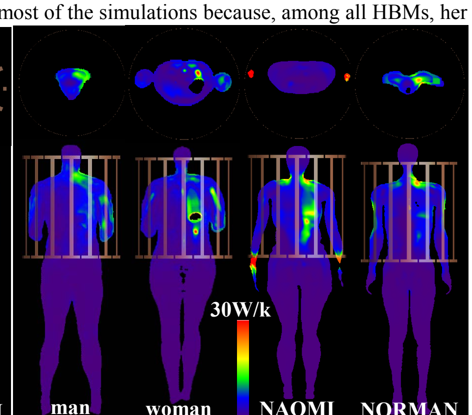

Fig. 3. Axial (top) and coronal (bottom) slices showing maximum SAR_{10g} for HBMs in **HPBC** coil at heart-centered landmark position.

Table 1. Maximum SAR_{10g} values for various landmark positions for HPBC and TEM body coils

	Max. SAR_{10g} (W/ kg) normalized to whole body $SAR_{average}$ of 2 W/ kg							
	Visible Man (1.77m)		**Visible Woman (1.73m)**		**NAOMI (1.58m)**		**NORMAN (1.74m)**	
Landmark	**HPBC**	**TEM**	**HPBC**	**TEM**	**HPBC**	**TEM**	**HPBC**	**TEM**
Head	38.12	44.22	32.10	29.96	46.98	65.42	38.79	32.99
Heart	15.55	19.11	30.17	22.79	53.38	68.51	23.97	31.24
Pelvic	33.27	23.68	40.96	20.69	33.61	97.77	40.13	30.74

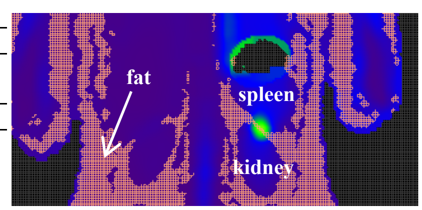

Fig. 4. Local SAR_{10g} hot spot at fat-soft tissue interface for heart-centric visible woman model in TEM coil.

Despite the lack of observable trends in local SAR values across coils, it was clear that several HBM factors consistently increased SAR. As seen in the NAOMI HBM in the TEM and HPBC coils, proximity to rung elements and capacitors will subject the body to high levels of inductive and conservative E-fields, which will increase SAR significantly. Another well-known source of high local SAR are the points of contact of body parts or external apparatus that form current loops, as observed in the hands of the visible man model in Fig. 2. Another source of high local SAR are the peak E-fields observed at the edge of tissues with dielectric constants that differ significantly (an order of magnitude), e.g., muscle-fat/bone, skin-fat interfaces. For example, the hot spot below the empty stomach in the visible woman model in Fig. 3 (magnified in Fig. 4) lies on a sliver of fat (ε_r=5.92) surrounded by the kidney (ε_r=89.68) and spleen (ε_r=82.95). Hot spots at such interfaces also depend on the direction of the incident E-fields. To cover all these potential factors, the use of a diverse set of HBMs is necessary for any comprehensive SAR safety evaluation of coils or imaging experimental conditions.

Conclusions: Local SAR is highly dependent on human body parameters and any generalization of local SAR differences between the HPBC and TEM coils under given experimental assumptions should be carefully validated with a diverse set of applicable HBMs in various positions. In spite of the absence of observable trends in the local SAR to whole body average SAR ratios across four HBMs in three landmarks positions, several human body factors were observed to predictably increase local SAR.

References: [1] W. Liu *et al*. Appl. Magn. Reson. 2005;29:5-18. [2] CM Collins *et al*., Magn Reson Med 2001;45:692 . [3] P Dimbylow, Phy Med Bio 1997;42: 479-490 [4] P Dimbylow, Phy Med Bio 2005;50:1047-1070 [5] IEC 60601-2-33, 2006-02.

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