SAR and Temperature Compared to Limits in Simulations of a Dedicated Extremity Coil

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Introduction: Ensuring that limits of RF power absorption (SAR) and temperature increase are not exceeded in imaging the extremities of the human anatomy can be difficult, as little information regarding the SAR distributions has been published in this area. This has led to gross extrapolations from data calculated for other parts of the body, such as the head, to determine operating limits in extremity imaging, including T1ρ imaging of the knee (1, 2). Here we evaluate what RF power levels can be used in imaging of the human knee with a dedicated extremity coil without exceeding IEC or FDA limits on SAR or temperature.

Methods: A cylindrical high-pass birdcage coil was simulated at 64 and 128 MHz (1.5 and 3.0 T) using the FDTD method when loaded with models of two different knees. The coil had 16 copper rungs, a 12 cm radius, and a 24 cm length. The radius and length of the shield were 15 cm and 30 cm, respectively. To accurately simulate the current distribution in an ideal high-pass birdcage coil, current sources were placed in the middle of the top and bottom ring segments (between rungs of the coil) with a 22.5° phase-shift between currents in adjacent end ring segments, and with segments in opposite end rings having opposite orientation. All models had an isometric resolution of 3mm. An eight-layer Berenger's PML was adopted as the absorption boundary and a Four-Cole-Cole extrapolation technique was used to determine values for the dielectric properties of the different human knee tissues (3). The model geometry used in the computer simulation was downloaded from the Brooks Air Force Laboratory. The model geometry is shown in Fig 1. The temperature distribution was modeled by using the Pennes bio-heat equation. Home-built 3D FDTD code (3) was used in all simulations.

Results and Discussion: Using the IEC limits for partial-body average SAR (4) over the knee, it was determined that an SAR averaged over the portion of the model within the coil (SAR_{knee}) of 8-10 W/kg would be permissible by the IEC, provided the maximum local SAR in any 10 g of tissue (SAR_{10g}) did not exceed 20 W/kg, or the maximum local temperature did not exceed 40° C. Thus we initially normalized all SAR to achieve SAR_{knee}=8W/kg, resulting in total absorbed power P_{abs} (easily estimated in experiment) are shown in Table 1. Resulting maximum local SAR levels and temperature increase in the entire anatomical model are also shown in Table 1. Because the resulting maximum local SAR levels and temperature in the leg at this level all exceeded regulatory limits (4, 5), we then reduced the input power to achieve a maximum local $SAR_{10\,g}$ of 20.00 W/kg to match the IEC limit for local SAR in the extremities, and found all the IEC limits on SAR and temperature to be satisfied. This corresponds to the SAR_{knee} of 4.09 W/kg at 64 MHz and SAR_{knee} of 5.25 W/kg at 128 MHz (Table 1). Satisfaction of the FDA requirements would require significant further reduction of total absorbed power. The axial plane distributions of SAR_{1g}, SAR_{10g}, and ΔT after 15 min and 30 min for a 4 W/Kg SAR_{knee} are shown in Fig 2. Compared to a previous work (6), the spatial correlation between SAR and temperature is better in the knee than in the head, though differences are still apparent. This improved spatial correlation is presumably due to the abundance of relatively low-perfusion tissues in the knee, such as muscle at rest, fat, and bone. Based on this work, satisfaction of the limits on partial body SAR alone will not ensure compliance with limits on local maximum SAR or temperature increase when using a dedicated extremity coil for excitation.

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References

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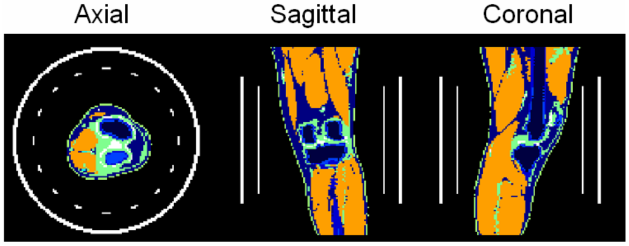

Figure 1 Model Geometry for one of two knees simulated in the extremity coil.

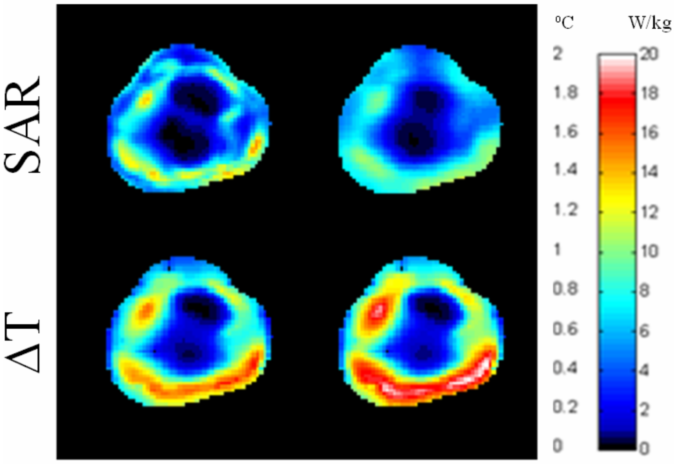

Figure 2 SAR (W/kg) averaged over 1g (top left) and 10g (top right), and temperature (°C) after 15 min (bottom left) and 30 min (bottom right) in a mid-axial slice through the knee at SAR_{knee}=4W/kg.

Table 1 Partial-body average (over knee) and maximum local SAR, total absorbed power, maximum local temperature, and average B_1 magnitude in the knee for all calculations. Temperature increase results for both knees were within 10% of each other: results shown are for knee with higher temperature increases for a given P_{abs}.

	SAR_{knee}	P_{abs}	SAR_{1g}	SAR_{10g}	mean	15min		30min	
frequency	(W/kg)	(W/kg)	(FDA)	(IEC)	B_1^+ (μT)	T(°C)	ΔT(°C)	T(°C)	ΔT(°C)
64 MHz	4.09	16.32	29.94	20.00	12.58	38.76	2.94	39.01	3.19
	8.00	31.90	58.55	39.09	17.59	41.64	5.88	42.12	6.37
128 MHz	5.25	22.27	35.48	20.00	6.59	39.79	3.38	40.43	4.02
	8.00	33.91	54.03	30.46	8.14	41.56	5.15	42.54	6.12
IEC limits	>8			20.00		40.00		40.00	
FDA limits			12.00						