RF Transmit Power Limit for the Bare-Wire Loopless Catheter Antenna

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Introduction:
The main safety concern when taking MR images with interventional devices in place is RF heating. The relevant FDA guidelines that apply to invasive devices limit the spatial peak specific absorption rate (SAR) to 8 W/kg in the head or torso and 12 W/kg in the extremities in any gram of tissue averaged over a 15-minute period.

Previous research has demonstrated substantial heating when imaging with intravascular devices, such as tracking catheters and guidewires, in place [1,2,3]. These studies have concentrated on MR scans that transmit RF pulses with the body coil. However, some catheter tracking devices are transmitters themselves and do not use the body coil as the RF source [4,5].

In this work, we examined the RF heating generated by the loopless catheter antenna design [6] in transmit mode only. An upper limit was placed on the RF transmit power such that the spatial peak SAR does not exceed the current regulatory limit.

Methods:
The SAR distribution was calculated from the electric field (E) distribution: SAR = |E|^2/μσ, where μ is the electrical conductivity and σ is the mass density of the medium. We used the analytical expression of King and Harrison for the electric field distribution of a halfwave dipole antenna at 64 MHz in a homogeneous dissipative medium [7]. To conform to FDA specifications, the resulting SAR distribution was then smoothed by spatially averaging the SAR at each point with those in the nearest one gram sphere of tissue.

An 8-inch diameter cylindrical phantom with a 1.5% agar gel doped with 0.45% NaCl was used to mimic the electrical properties of tissue (μ = 0.8 S/m at 64 MHz). RF power was applied to the antenna from a stand-alone frequency synthesizer and RF amplifier. Power was measured using a directional coupler and power meter. Temperature changes were sampled once every 0.8 seconds using a multi-channel fiber-optic temperature probe system (FISO Technologies, Ste-Foy, PQ, Canada) connected to a personal computer. SAR was calculated by multiplying the initial slope of the temperature curve by the gel’s heat capacity.

Results:
The predicted SAR distribution with ω=80, σ=0.8, ω=2π·64 MHz is shown in figure 1. It shows highly concentrated heating near the antenna that rapidly decays with radial distance. There is little variation parallel to the antenna itself.

Figure 1: Theoretical SAR distribution surrounding an ideal half-wave dipole antenna in a homogeneous lossy medium, normalized to 1W input power (log₁₀ W/kg).

We examined RF safety of the catheter antenna only in transmit mode. In receive mode, RF heating can be decomposed into two components: the intrinsic SAR from the body coil and the additional SAR due to coupling of the body coil to the catheter. This second component will have a distribution very similar to that of the antenna in transmit mode except that there may be a large gain due to the coupling coefficient between the body coil and the antenna. Therefore, this work also serves as a first step toward understanding RF heating in receive mode.

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